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BULLETIN

OF THE

AMERICAN PHYSICAL SOCIETY

INCLUDING THE

PROGRAMME OF THE

1956 THANKSGIVING MEETING

AT

CHICAGO, ILLINOIS

November 23 and 24, 1956

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BULLETIN

OF THE

AMERICAN PHYSICAL SOCIETY

1956 Thanksgiving Meeting at Chicago, Illinois, November 23–24, 1956

FOR the **1956 Thanksgiving meeting** of the American Physical Society we shall enjoy, as we did last year and in many previous years, the great hospitality of the University of Chicago and the able administration of Mrs. Dorothy C. Johnson, to which and to whom our debt continues to increase. The dates will be **Friday and Saturday, November 23 and 24.** Headquarters of the meeting will be the Enrico Fermi Institute for Nuclear Studies at 5630 Ellis Avenue: there our members will find the registration desk, the bulletin boards, and conference rooms that will be available for intellectual and social gatherings. Ellis Avenue runs along the west side of the "old" campus of the University, and the Enrico Fermi Institute is on its west side half a block north of the corner of that campus. The halls for the scientific sessions are on the "old" campus.

The problems of Mrs. Johnson and her Local Committee are more troublesome this year than heretofore, not because the number of ten-minute papers has augmented, but partly because of the two Symposia occupying three half-day sessions altogether, and partly because Kent Theatre is not available on Friday. Session N is prolonged to the length of fifteen papers on the plausible hypothesis that the theoretical physicists would rather finish on Saturday morning than continue into Saturday afternoon. No topic (of contributed papers) that was assigned to Saturday afternoon in 1954 or 1955 gets the same position this year, and the like might have been said of Friday morning but that the Symposium of the Division of Solid-State Physics, allotted to Saturday, seemed to require the transposition to Friday of as many as possible of the other solid-state papers.

All **reservations of hotel rooms** are to be made through the Hotels Windermere, 1642 East 56 Street, Chicago 37, Illinois. It is essential to mention the Society in your letters asking for room reservations. "Single rooms are $6.50 and $7.50, double rooms are $8.50 and $10.00—the majority, of course, are in the $7.50 and $10.00 brackets. Television-equipped rooms are $1.00 additional. Suites consisting of living room and bedroom are $15 single and $17 double." After these accommodations are fully bespoken, Hotels Windermere will assume the responsibility of placing our members at other hotels of the region. This "region" is about three-quarters of a mile east of the University. The best ways to go between it and the University are by foot and by taxi. There is also a bus from 56th Street and Lake Park Avenue to 55th Street and Ellis Avenue. Those coming by rail from the East should detrain at Englewood, not downtown.

The **registration desk** will be located, to repeat, in the Enrico Fermi Institute at 5630 Ellis Avenue. All members and guests are asked to register. A registration fee of one dollar will be demanded. Consult the nearby bulletin boards for notice of post-deadline papers, of messages, and of possible changes in the halls.

Invited papers on the general programme will be given by W. W. Beeman, Gilberto Bernardini, William Chinowsky, C. H. Hammer, H. M. James, L. M. Langer, J. J. Livingood, F. B. McDonald, D. J. Montgomery, T. B. Novey, Keith Symon, and Robert Tripp.

Our **Division of Solid-State Physics** has arranged a Symposium which will be held in Kent Theatre on Saturday morning and afternoon. The list of speakers will be found in the Epitome, that of speakers and titles in the main text (page 345).

Our **Division of Chemical Physics** has arranged a Symposium, "Recent Advances in Molecular Spectroscopy," which will be held in Eckhart 133

on Friday afternoon. The speakers are listed in the Epitome, the speakers and titles in the main text (page 328).

One hundred and seventy-five contributed papers are distributed among fifteen sessions. This figure, when compared with the 168 of two years ago and the 183 of last year, sustains the hint of a welcome stabilization in the size of our meetings which was pointed out one year ago.

The **banquet of the Society** will be held at the Quadrangle Club, 1155 East 57th Street at the southeast corner of University Avenue, at seven o'clock on Friday evening: the price will be $3.50. This is one of the meetings at which the banquet must perforce be held on the first evening, thus allowing almost no time for indecision. Therefore, please use the reservation form on page 369 of this Bulletin or, if you do not, register and buy your tickets early on Friday morning. The after-dinner speakers will be E. U. Condon and J. E. Goldman.

Post-deadline ten-minute papers, pertaining to very recent achievements of very special importance, will be considered for admission to a special supplementary programme if the abstracts are received before Saturday, November 17, at the office of the Society. Mark these abstracts clearly for the Chicago post-deadline programme, as the abstracts for the Annual Meeting will be coming in at the same time. The titles of such papers as may be accepted will be written on the bulletin board, and opportunity for the giving of these papers will be granted at the end of Session A.

The **Council of the American Physical Society** will meet at 11 A.M. on Friday in Room 180 of the Enrico Fermi Institute (5630 Ellis Avenue) unless contrary notice is distributed to its members.

The preliminary announcements of the **Monterey and New York meetings** are printed further along in this Bulletin. Consult the Table of Contents for the location of these and other important items, including the new regulations for the "student concession."

Errata pertaining to abstracts in this issue will be published in a subsequent issue of the Bulletin if received not later than Monday, November 26, by Miss Ruth Bryans, American Institute of Physics, 57 East 55th Street, New York 22, New York. Do not send in the abstracts marked with corrections. Write out the corrections in the form "Instead of . . . read. . . ." Add nothing.

KARL K. DARROW, *Secretary*
American Physical Society
Columbia University
New York 27, New York

EPITOME OF THE 1956 THANKSGIVING MEETING

(Personal names are those of invited speakers, except at the ends of lines where they are those of halls.)

Friday Morning

A. James, Beeman; post-deadline papers, if any. Eckhart.

B. Cosmic rays; heavy mesons and hyperons. Oriental.

C. Semiconductors, I. Mandel.

D. Ferroelectricity, magnetism, magnetic resonance. Cobb.

E. Reactions of transmutation, I. Social Sciences.

Friday Afternoon

G. Reactions of transmutation, II. Social Sciences.

H. Division of Chemical Physics: recent advances in molecular spectroscopy: Hornig, Wilkinson, Plyler, Richardson. Eckhart.

J. Radioactive nuclei. Cobb.

K. Semiconductors, II. Mandel.

L. Metals. Oriental.

Friday Evening

Banquet of the American Physical Society: Condon, Goldman. Quadrangle Club.

Saturday Morning

M. Tripp, Chinowsky, McDonald. Mandel.

N. Theoretical physics. Cobb.

P. Scattering of nuclei and neutrons; photoneutrons. Social Sciences.

Q. Montgomery; general physics. Eckhart.

R. General nuclear physics; nuclear instrumentation. Oriental.

T. Division of Solid-State Physics: Fisher, Picus, Maurer, Klemens. Kent.

Saturday Afternoon

U. Division of Solid-State Physics: Phillips, Powers, Bowers, Schmitt. Kent.

V. Langer, Novey Hammer. Eckhart.

W. Bernardini, Livingood, Symon. Mandel.

X. Neutron physics. Social Sciences.

Y. Low-temperature physics; solid-state physics. Cobb.

Z. Mesons; electron pairs. Oriental.

PROGRAMME

FRIDAY MORNING AT 10:30

Eckhart 133

(DAVID LAZARUS presiding)

Invited Papers in Solid-State Physics

A1. Order-Disorder Transitions in Molecular Crystals. H. M. JAMES, *Purdue University.* (30 min.)
A2. Small-Angle X-Ray Scattering from Cold-Worked Metals. W. W. BEEMAN, *University of Wisconsin.* (30 min.)

Post-deadline papers, if any

FRIDAY MORNING AT 10:30

Oriental 272

(J. A. VAN ALLEN presiding)

Cosmic Rays; Heavy Mesons and Hyperons

B1. On the Penumbra and Simple Shadow Cone of Cosmic Radiation.* MELVIN SCHWARTZ,† *State University of Iowa.*—The main structure of the penumbra has been determined in the vertical direction at geomagnetic latitudes 30°, 35°, 41°, 45°, 50°; zenith angles 45° and 60°, north, east, south, west at geomagnetic latitude 41°. The results are based on trajectory calculations performed by AVIDAC at Argonne National Laboratory. The 60° zenith angle results at 41° contradict Schremp's shadow cone calculations.[1] The present calculations are sufficiently accurate to indicate that Schremp's results are in error. There is no simple shadow cone cutoff at zenith angle 60° or lower at latitude 41°. This result has also been verified at latitude 40°. The vertical direction results have been used to determine effective cutoffs and a new power law integral rigidity spectrum with exponent 1.02. This spectrum has been used to fit vertical particle intensities and vertical $z \geq 6$ intensities as well as total vertical intensities. The ratio of the three constants in the three spectral functions is consistent with current experimental data.

* Assisted by the joint program of the Office of Naval Research and the Atomic Energy Commission.
† Now at Rutgers University.
[1] E. J. Schremp, Phys. Rev. **54**, 158 (1938).

B2. Helium in the Primary Cosmic Radiation near the Geomagnetic Equator. M. M. SHAPIRO, B. STILLER, AND F. W. O'DELL, *Naval Research Laboratory.*—Published values of the equatorial flux ϕ of primary helium nuclei vary from 14 ± 20 to 49 ± 13 peters [particles/m² sec sterad]. We therefore undertook to measure this flux in a stack of stripped emulsion exposed at ~10°N geomagnetic on September 7, 1953, at a mean pressure altitude of 14.7 ± 1.5 g/cm² for 6.2 hr. Tracks which met suitable ionization and dip criteria were followed through the stack. Most singly charged particles were identified by their change in ionization loss with range; the rest were eliminated by multiple scattering measurements, which readily distinguish them from relativistic He with the same ionization. The observed He flux has been corrected for detection efficiency, attenuation above the stack, contributions from fragmentation of heavier primary nuclei, and a geometric factor. The preliminary value, averaged over zenith angles <60°, is $\phi = 19.2 \pm 2.4$ peters. (A breakdown gives, in 0°–30°, $\phi = 18.7$; in 30°–60°, 19.7 peters.) A correction for particles arriving during ascent and descent of the balloon would lower this estimate. The collision mean free path in emulsion of these energetic nuclei (kinetic energy >6 Bev/nucleon) is 75 ± 8.4 g/cm², in agreement with mfp's down to He energies of 90 Mev/nucleon.

B3. Time Variations of Cosmic Rays as Detected by a Small-Angle Telescope. JOHN KATZMAN, *National Research Council, Canada.*—A small-angle telescope (2° half-angle) with 96 in. of lead as absorber was used to study time variations at Ottawa, geomagnetic north 56.8°. No variation with sidereal time was found. A semidiurnal variation of amplitude of 16% was obtained. This variation is approximately 180° out of phase with the semidiurnal pressure variation. The intensity maxima occur at 0200 and 1500 hr and the minima at 0700 and 2000 hr, solar time.

B4. High-Energy Photon Jet in Cosmic Rays. O. B. YOUNG AND T. S. YOON, *Southern Illinois University.**—This report concerns a high-energy photon shower similar to an event previously reported,[1] but with interesting points of difference, including lower energy, axis zenith angle larger than 90°, and a smaller number of electron pairs. The event consists of seven electron pairs in a stack of three Ilford G-5, 600μ pellicles, exposed at 114 000 ft altitude at geomagnetic latitude of N41°. Observations were restricted to the three plates; however, the total length observed was 30 000μ. The energies of the seven pairs of electron tracks range from 126 to 3630 Mev and total nearly 11 Bev. The 98° zenith angle of the axis indicates the source to be a nuclear interaction at lower altitude than the balloon.

* Supported by the Office of Ordnance Research. Research cooperatively performed with the University of Chicago.
[1] Schein, Haskin, Glasser, Phys. Rev. **95**, 855 (1954).

B5. Hypernuclei from π^- Interactions. I. Mesic Decays.* W. SLATER, E. SILVERSTEIN, R. LEVI-SETTI, AND V. L. TELEGDI, *The University of Chicago.*—Systematic searching since April, 1956, for hypernuclei among 1.3×10^5 interactions of 4.7 Bev

π^- in emulsion has yielded 25 mesic decays. Seventeen could be analyzed as follows:

Identity	Decay scheme	No. of events	$\langle B_\Lambda \rangle$ (Mev)[1]	σ (Mev)	Δ (Mev)
${}_\Lambda H^4$	π^-+He^4 $\pi^-+H^1+H^3$	4 2	1.00	0.20	0.12
${}_\Lambda He^4$	$\pi^-+H^1+He^3$	3	1.80	0.25	0.11
${}_\Lambda He^5$	$\pi^-+H^1+He^3$	5	2.61	0.25	0.11
${}_\Lambda Li^8$	π^-+2He^4	1	4.5	0.8	0.15
${}_\Lambda Be^8$	$\pi^-+H^1+He^3+He^4$	1	5.8	0.4	0.1
${}_\Lambda Be^9$	$\pi^-+H^1+2He^4$	1	6.0	0.4	0.1

σ = standard deviation. Δ = error due to stopping power uncertainty. Five others decay into π^-+H^1+very short recoil; in two more, the π's interact in flight; and one is unmeasureable. Preliminary testing of measurement techniques with τ's has given the Q values: 75.25, 74.53, and 75.03 Mev. Energies have been computed from the UCRL tables[2]; a preliminary range correction of $(1\pm.5)\%$ is determined from 70 μ ranges and from density measurements.

* Supported by the Greenewalt Nuclear Physics Fund, the Office of Naval Research, and the U. S. Atomic Energy Commission.

[1] Weighted mean; straggling and kinematic identifiability of recoil were used in weighting.

[2] W. H. Barkas, University of California Radiation Laboratory Report No. 3384 (April, 1956).

B6. Hypernuclei from π^- Interactions. II. Nonmesic Decays. E. SILVERSTEIN, W. SLATER, R. LEVI-SETTI, AND V. L. TELEGDI, *The University of Chicago.*—In the course of a systematic search,[1] about 140 double stars were found in which the connecting track was heavily ionizing and in which the secondary star disintegrates without $\pi^\pm$ emission; roughly 25 of these, with ranges $(R)>20\mu$, allow immediate classification as hypernuclei. Statistical classification of the remainder into hypernuclei, π^- stars, and secondary nuclear interactions is being attempted on the basis of the following criteria: (1) R distribution of connecting track; (2) ranges and number of prongs from secondary star; (3) frequency of fast protons from secondary stars; (4) angle between incident π^- and connecting track. Data on absolute yields, Z distribution, and binding energies of hypernuclei will be presented.

[1] Slater, Silverstein, Levi-Setti, and Telegdi (preceding abstract).

B7. Evidence for Long-Lived Neutral K Mesons. R. G. GLASSER AND N. SEEMAN, *Naval Research Laboratory.*—In an emulsion stack exposed to the 90° K^- beam of the Berkeley bevatron, two events were found which support the hypothesis of the existence of a long-lived neutral K-meson. The first event is a 4-prong star initiated by a neutral particle. Two of the prongs are a Σ^+ hyperon and a 70-Mev pion. The Σ^+, after 2.41 mm, interacts with an emulsion nucleus and continues, coming to rest after another 1.35 mm. A proton of 1.64 mm emerges as a decay track. This is, to our knowledge, the second example of a Σ^+ interaction; in both cases the Σ^+ continues after the scatter. The second event, also initiated by a neutral particle, consists of a star containing a helium hyperfragment, a 60-Mev π meson, and 3 evaporation tracks. The hyperfragment comes to rest after 130μ and undergoes nonmesonic decay, emitting two singly charged particles and at least two neutral particles. These two cases, together with the four of Fry *et al.*,[1] constitute evidence for a neutral K meson living long enough to reach our stack ($\sim 10^{-8}$ sec) and capable of producing hyperons in an interaction.

[1] Fry, Schneps, and Swami (to be published).

B8. Lifetimes of τ, $K_{\mu 3}$, and K_{π} Decay Modes.* T. F. HOANG,† M. F. KAPLON, AND G. YEKUTIELI,‡ *University of Rochester.*—Two stacks of stripped emulsions were separately exposed to the K^+-meson beam of the Brookhaven Cosmotron, at different distances from the target. The K^+ mesons were selected by a systematic "on-track" scan and analyzed according to their decay modes. Lifetimes (T) of different decay modes were estimated by comparing their ratios observed in the two stacks and using the lifetime of $K_{\mu 2}$ and $K_{\pi 2}$ found by counter experiments[1] as a secondary standard. The results obtained are

$$(\tau+\tau') \quad T=(1.30\pm0.33)\times10^{-8} \text{ sec},$$
$$K_{\mu 3} \quad T=(0.88\pm0.23)\times10^{-8} \text{ sec},$$
$$K_{\pi} \quad T=(1.44\pm0.46)\times10^{-8} \text{ sec},$$

and indicate that the lifetimes of different decay modes are all consistent within experimental errors with a unique value.

* Supported in part by U. S. Atomic Energy Commission and the Office of Scientific Research of the U. S. Air Force.

† On leave from Laboratoire Leprince-Ringuet, Ecole Polytechnique, Paris.

‡ Present address: Weizmann Institute of Science, Rehovoth, Israel.

[1] Alvarez, Crawford, Good, and Stevenson, Phys. Rev. **101**, 503 (1956); V. Fitch and R. Motley Phys. Rev. **101**, 498 (1956).

B9. Production of Unstable Particles by Protons on Various Nuclei. DAVID BERLEY AND GEORGE B. COLLINS, *Brookhaven National Laboratory.*—The investigation of unstable particle production by the detection of gamma rays from the decay of these particles at distances a few centimeters from a target has been continued at the Cosmotron.[1] Relative gamma-ray yields from H, D, Li^6, Li^7, Be, C, Al, Cu, Ag, and Pb have been measured when these nuclei are bombarded with 3-Bev protons. The $p-p$ and $p-d$ yields were measured by both $C-CH_2-CD_2$ and $Li-LiH-LiD$ differences. Under the assumption that these particles are hyperons or heavy mesons, the total cross section of that component which decay via π^0 mesons is estimated at $\sim 20\mu$b per deuterium nucleus. The $p-p$ differential gamma-ray cross section is less than $\frac{1}{6}$ the $p-d$ cross section and consistent with zero. The variation of the gamma-ray cross section per nucleus is linear with atomic number from deuterium to aluminum and proportional to $\sim A^{0.7}$ from copper to lead. This increase with atomic number is definitely more rapid than that of the total inelastic p-nucleus or n-nucleus cross section. An analysis of the mean survival distance for particles produced on several nuclei suggests that scattering is unimportant and that the differential gamma-ray cross sections are proportional to the total production cross sections.

[1] Ridgway, Berley, and Collins, Phys. Rev. **104**, 513 (1956).

FRIDAY MORNING AT 10:00

Mandel Hall

(V. A. JOHNSON presiding)

Semiconductors, I

C1. Theory and Experiments on Noise in CdS Photoconconducting Crystals.* K. M. VAN VLIET,† AND J. BLOK, *Vrije Universiteit, Amsterdam, The Netherlands* (introduced by A. van der Ziel).—Fluctuations in the carrier densities in photoconductors are partially due to fluctuations in the number of incident light quanta and partially due to the statistical nature

of the recombination and trapping processes. Using the kinetic equations, well known in the theory of photoconductivity, the Langevin equations are obtained from which the noise spectrum has been computed. Measurements of noise on silver-activated and undoped crystals gave spectra which are not of the $1/f$ type, but which can be explained by the foregoing theory. The spectra depend on the light intensity and on the wavelength. In particular, noise spectra obtained with light of a wavelength beyond the absorption limit differ entirely from spectra with irradiation in the fundamental absorption band. In the first case there is a flattening at low frequencies (10 c/s) related to the relaxation time for recombination, whereas the noise in the 10-kcps, 1-Mcps region is related to trapping relaxation times. Measured response curves support this interpretation.

* Supported in part by N. V. Philips, Eindhoven, The Netherlands.
† Now at the University of Minnesota.

C2. A Temperature Consideration in Solar Battery Development. R. E. HALSTED, *General Electric Research Laboratory.*—Discussions to date on the use of photovoltaic cells for solar energy conversion have emphasized the attainment of an optimum conversion efficiency for approximately 300°K operation. At this temperature semiconductors with band gaps in the range 1.1 to 1.6 ev have been found to offer the best possibility of exceeding the efficiency of silicon.[1] Practical interest in elevated temperature operation[2] has suggested an examination of the influence of this parameter upon the choice of an optimum band-gap material. One finds at elevated temperatures that the reduction in reverse saturation current achieved with semiconductors of larger band gaps can more than compensate for the loss of useful solar photons. The band gap at which maximum efficiency might theoretically be achieved increases approximately 0.15 ev per 100°K increase in operating temperature. This result, coupled with the rapid loss of efficiency of silicon with an operating temperature increase,[3] provides an additional basis for interest in materials of band gap appreciably greater than silicon for photovoltaic solar energy conversion.

[1] J. J. Loferski, J. Appl. Phys. **27**, 777 (1956).
[2] Kingdon, Flagg, Branch, Douglas, and Halsted (to be published).
[3] M. B. Prince, J. Appl. Phys. **26**, 534 (1955).

C3. After Effects of Gamma Irradiation upon the Electrical Conductivity of Plexiglas.* R. J. MUNICK, *Argonne National Laboratory.*—A specimen of Plexiglas that had been the subject of previous electrical measurements was given doses of 10^6 roentgens and greater in the Argonne High Level Gamma Irradiation Facility. Electrical measurements after an accumulated dosage of 10^7 roentgens indicated that there had been a permanent increase in polarization and conduction currents, the conduction current having increased about 30% over the value before irradiation. The change of conduction current with temperature over the range from 30 to 51°C gave the same thermal activation energy that was found before irradiation. This result differs from the decrease in activation energy that is found[1] in polymethyl methacrylate that is undergoing x-irradiation.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] J. F. Fowler and F. T. Farmer, Nature **175**, 516 (1955).

C4. Cyclotron Resonance in Graphite. W. A. YAGER, J. K. GALT, AND F. R. MERRITT, *Bell Telephone Laboratories.*—Cyclotron resonance absorption has been observed in crystalline flakes of graphite at 1.3°K with circularly polarized waves at 24 000 and 72 000 Mcps. A brief description of the test cavity, method of obtaining circular polarization, and measurement techniques will be given. The data have a rather complex structure consisting of a broad variation in power absorption coefficient at both positive and negative magnetic fields (majority carriers) plus at least three sharper singularities at low fields on each side of zero (minority carriers[1]). The complexity of the spectrum makes quantitative comparison of experiment with theory difficult. Some theoretical aspects of this problem will be discussed in the following abstract. A crude analysis leads us to believe that the masses of the majority carriers are less than that for a free electron, m_0, and that the masses of the minority carriers are about 0.05 m_0, 0.03 m_0, and less than 0.02 m_0. Observations at the two frequencies show that the singularities obey the cyclotron resonance equation.

[1] P. W. Anderson, Phys. Rev. **100**, 749 (1955).

C5. Some Aspects of the Band Structure of Graphite: Application to the Cyclotron Resonance. PHILIPPE P. NOZIÈRES, *Bell Telephone Laboratories.*—A detailed group theoretical study of the three-dimensional graphite is carried out. For every value of the component K_z of the wave vector parallel to the C axis, an expansion in powers of K_x and K_y of the energy E is obtained to second order. This depends on only three parameters, which are roughly evaluated using the results of Lomer[1] and Slonzcewski.[2] The corresponding energy surfaces are highly anisotropic in the K_xK_y plane. Using this expression, the problem of classical cyclotron resonance is solved entirely and shows the existence of a continuous distribution of masses around the Fermi level. Yager *et al.*[3] have observed sharp peaks in the resonance curve. Several tentative explanations of these results are proposed.

[1] W. M. Lomer, Proc. Roy. Soc. (London) **A227**, 330 (1955).
[2] J. C. Slonzcewski, thesis, Rutgers University (unpublished).
[3] Yager, Galt, and Merritt (preceding abstract).

C6. Electrical and Optical Properties of Silicon Containing Oxygen as Impurity. W. KAISER AND P. H. KECK, *Signal Corps Engineering Laboratories.*—It has been demonstrated[1] that silicon crystals pulled from a quartz crucible contain up to 10^{18} oxygen atoms per cm³. The 9μ absorption band of silicon was correlated with the oxygen content of the crystal. More quantitative measurements indicated that in a liquid zone of silicon (about 20 mm² in cross section) the oxygen concentration can be strongly decreased in helium, hydrogen, or vacuum and increased in an oxygen atmosphere in a matter of minutes. In solid silicon the diffusion constant of oxygen is estimated to be $D=2\times10^{-7}$ cm² sec^{-1} at 1400°C. Heat treatment at around 1000°C gives rise to the formation of silicon oxide clusters, having a smaller dielectric constant than the silicon matrix. Optical scattering, as a consequence, was found between 1 and 3μ, and the Tyndall effect was observed in such samples with an infrared image tube. Small-scale fluctuations in the oxygen concentration, associated with the growth rings of the crystal,[2] result in a corresponding scattering pattern. Differences in oxygen content of silicon crystals were found to be related to changes in resistivity after a 450°C heat treatment.

[1] Kaiser, Keck, and Lange, Phys. Rev. **101**, 1264 (1956); H. J. Hrostowski and R. H. Kaiser, Bull. Am. Phys. Soc. Ser. II, **1**, 295 (1956).
[2] W. C. Dash (private communication).

C7. Electron Bombardment of Silicon.* D. E. HILL, *Purdue University.*—Single crystal silicon samples have been bombarded at the ice point with 4.5-Mev electrons from the Purdue linear accelerator. Measurements of the Hall coefficient and the resistivity were made at intervals during the bombardment. From these one can calculate the position of the Fermi level, ζ, and the rate of removal of carriers/cm³ per incident electron/cm². The removal rate, $dn/d\phi$, as a function of the position of ζ was determined. In an n-type sample with initial ζ in the conduction band one finds a $dn/d\phi$ of $\sim$14. Other samples with initial ζ below the edge of the conduction band have lower $dn/d\phi$ values, the value being $\sim$0.02 for a ζ of 0.3 ev. P-type silicon shows a similar behavior, with a

degenerate sample giving $dp/d\phi \sim 18$. Most of the bombardment introduced levels are close to the band edges. Further evidence suggests the presence of other levels in the forbidden gap. With prolonged irradiation both *n*- and *p*-type samples approach intrinsic behavior, as also observed in heavy particle bombardment.

* Supported by a U. S. Atomic Energy Commission contract.

C8. Effect of Electric Fields on Surface States on Silicon. H. STATZ, G. A. DEMARS, L. DAVIS, JR., AND A. ADAMS, JR., *Raytheon Manufacturing Company.*—Measurements on inversion layers across the base region of $p-n-p$ and $n-p-n$ bars of silicon have been made. At high bias voltages, the charge in the outer surface states becomes large, and also the field across the oxide film is high. Both for *p*-type and *n*-type inversion layers, changes in the structure of the surface states are observed when the bias voltage is made sufficiently high. Experimentally, these changes become evident through a decrease of the conductance of both types of inversion layers. Measurements of the inner surface states show that the high fields have no influence on surface states in the lower half of the gap, but only on surface states in the upper half of the gap. The number of the surface states in the upper half of the gap decreases in the high field. At low bias voltages, their density is slowly restored. After oxidation of the surface, the high field effect is enhanced. This indicates a correlation of this effect with the mechanism of oxide growth. Various models for the observed effects will be discussed.

C9. Surface States in the Upper Half of the Energy Gap of Germanium. G. A. DEMARS, H. STATZ, L. DAVIS, JR., AND A. ADAMS, JR., *Raytheon Manufacturing Company.*—Surface states in the upper half of the energy gap of germanium have been investigated by measuring inversion layer conductance on *p*-type material. Inversion layers are formed on etched surfaces by exposure to dry ammonia or acetylene. For these measurements, it is desirable to oxidize the surface after etching in order to get reasonably long times of filling and emptying the outer surface states. There appear to be more surface states after oxidation. The measurements indicate localized states varying in energy from 0.12 to 0.18 v above the middle of the gap. In some instances before oxidation there appears to be a distribution of surface states increasing in density towards the conduction band. The time dependence of filling and emptying the outer surface states will be discussed.

C10. The Argon Bombardment and Oxidation of Germanium Surfaces. S. P. WOLSKY, *Raytheon Manufacturing Company* (introduced by H. Letaw, Jr.).—A sensitive quartz microbalance set up in a vacuum system capable of attaining pressures of 5×10^{-10} mm has been used to study the argon bombardment technique[1] for the preparation of clean germanium surfaces. The efficiency of the bombardment process expressed as the number of germanium atoms removed per argon ion striking the surfaces appears to be unity under the conditions of the experiment. The quantity of argon remaining in the lattice after bombardment has been found to be as large as 10^{13} atoms/cc. The room temperature oxidation of bombarded surfaces at 3-mm oxygen pressure has yielded values in agreement with those of other workers.[2]

[1] Farnsworth, Schlier, George, and Burger J. Appl. Phys. **26**, 252 (1955).
[2] M. Green and J. A. Kafalas, Phys. Rev. **98**, 1566 (1955).

C11. Use of Au-Ge Surface Barriers as Alpha-Particle Spectrometers. J. MAYER* AND B. GOSSICK,† *Purdue University.*—Alpha-particles incident on the semiconductor surface liberate hole-electron pairs proportional to the energy of the alpha particle. Carriers diffuse to the barrier at the germanium surface and create a measurable voltage pulse. The pulse height is linear with alpha energy up to 7.5 Mev and increases monotonically with energy to 12 Mev. At 16 Mev, the pulse height saturates and decreases with increased alpha energies, due to the finite transit time of the more deeply formed carriers. The surface barrier is biased in the reverse direction. The pulse height increases with increasing bias (and decreasing barrier capacity) following $V=Q/C$. The optimum signal-to-noise ratio for 5-Mev alpha particles is found between 10/1 and 20/1 which results in a detection lower limit of 0.5 Mev. The pulse height is approximately constant for monoenergetic alpha particles. The dispersion is comparable to that of scintillation crystals. The performance of the barriers did not deteriorate after total alpha fluxes of 10^{13} particles/cm^2, although recalibration by injecting known amounts of charge with a 0.1μsec pulse was necessary.

* Supported by Duncan Manufacturing Company.
† Now at Motorola, Inc.

FRIDAY MORNING AT 10:30

Cobb 110

(C. P. SLICHTER presiding)

Ferroelectricity; Magnetism; Magnetic Resonance

D1. Ferroelectricity in Colemanite. GEORGE J. GOLDSMITH, *RCA Laboratories.*—Colemanite ($CaB_3O_4(OH)_3\cdot H_2O$, monoclinic, $C_{2H}^5-P2_1/A$),[1] a common borate mineral, has long been known to exhibit large pyroelectric effects. J. W. Davisson,[2] in studies of breakdown paths in this material, indicated that an anomaly exists in the dielectric constant over a limited temperature range and that, in spite of large pyroelectric effects, a centrosymmetric breakdown pattern is observed at temperatures below the anomaly. We have observed the following ferroelectric behavior in colemanite: $T_C=-2.5$°C, ϵ' above transition = 20, ϵ' below transition = 18, $\epsilon'_{max}\simeq7000$, $P_s=5\times10^{-7}$ coulombs/cm^2. The ferroelectric direction is along the monoclinic *b* axis. The dielectric anomaly is very sharp, having a half-width of less than 0.5°C. The transition is evidently second order and the Curie-Weiss law is obeyed. Hysteresis loops are square with coercive field at 60 cycles and −6°C of about 10^4 v/cm. Asymmetric hysteresis loops are observed frequently, and the coercive field rises rapidly with decreasing temperature. Indications are that the material remains monoclinic below the ferroelectric transition.

[1] C. L. Christ, Am. Mineral. **38**, 411 (1953).
[2] J. W. Davisson, Bull. Am. Phys. Soc. Ser. II, **1**, 177 (1956).

D2. Sample-Length Effect on Permeability Measurement.* S. P. YU, D. CHEN, A. H. MORRISH, AND W. E. SWANSON, *University of Minnesota.*—A sample-length effect has been observed in the initial permeability measurement of finely powdered γ-Fe_2O_3 and paraffin mixtures. The peaking of the

loss angles at sample lengths equal to multiples of quarter wavelength cannot be accounted for by higher order modes or dimensional resonance. Calculation reveals that the loss angle is sensitive to nonideal termination of the transmission line and the error in the location of voltage minimum at these lengths. For optimum accuracy, a one-eighth wavelength sample should be used even though the "exact" method[1] is employed.

* This research was supported in part by the U. S. Air Force monitored by the A. F. Office of Scientific Research of the Air Research and Development Command.

[1] J. B. Birks, Proc. Phys. Soc. (London) **60**, 286 (1948).

D3. Theory of Infrared Resonances in Ferrimagnetics. ERNST SCHLÖMANN, *Raytheon Manufacturing Company.*—The frequency dependence of the magnetic susceptibility for circular excitation of an uncompensated ferrimagnet is derived from the Kramers-Kronig relations for gyrotropic media. In the lossless case the susceptibility is completely determined by two sets of parameters: the resonance frequencies and the corresponding optical strengths. These parameters are calculated for systems of two and three sublattices. In agreement with the results of Kaplan and Kittel[1] it is found that the high-frequency mode of the two-sublattice system is optically inactive unless the splitting factors or the anisotropy fields are different for the two sublattices. A system of three sublattices, corresponding to the case of ordered ferrites, is discussed in detail. Anisotropy fields are neglected in this discussion. One of the two exchange constants contained in the model can be eliminated from the Néel temperature. The infrared resonance frequencies can thus be expressed in terms of the Néel temperature and the ratio of the exchange constants. For representative cases the expected resonance frequencies are in the range of 10^{12} sec^{-1}. A method of detecting the high-frequency resonances by means of the magneto-optical Kerr effect is discussed.

[1] J. Kaplan and C. Kittel, J. Chem. Phys. **21**, 760 (1953).

D4. Influence of Magnetic Particle Interaction on Critical Single-Domain Size. L. A. K. WATT AND A. H. MORRISH, *University of Minnesota.*—If a powder containing single-domained magnetic particles with shape anisotropy is compressed, the coercive force is expected to decrease approximately linearly as the powder density increases. If the powder contains multidomained particles, the coercive force is expected to be independent of density.[1] With these criteria as a basis for the interpretation of the results, samples of four powders containing acicular γ-Fe_2O_3 particles of different mean size, but all close to the theoretical single-domain size, were compressed and the coercive force measured as a function of powder density. It was concluded that the powder consisting of the smallest particles contained single-domained particles while the powder consisting of the largest particles contained multidomained particles. The results also indicated that the two intermediate powders contained particles which were multidomained at low densities but became single-domained as the density increased. It is therefore concluded that the critical single-domain size of a magnetic particle is increased by the interaction of other particles. This result is in agreement with a theory due to Kondorskii.[2]

[1] A. H. Morrish and S. P. Yu, J. Appl. Phys. **26**, 1049 (1955).
[2] E. Kondorskii, Izv. AN S.S.S.R., ser fiz. **16**, 398 (1952).

D5. Effects of Ferrite Sample Size on the Frequency Shift of a Resonant Cavity. J. E. TOMPKINS AND E. G. SPENCER, *The Diamond Ordnance Fuze Laboratories.*—The results of measurements, made in a circularly polarized resonant cavity, of the components of the tensor permeability of a magnetized ferrite are interpreted. A treatment by Casimir is extended and applied to cavity perturbation theory, from which a complex frequency-shift expression is derived. In this expression nonuniformity of the internal rf fields in spherical and cylindrical samples is taken into account. For a sphere of radius R, the shift is given by

$$\frac{\delta f}{f}=\frac{K/2(\mu-1)(\gamma R\cosh\gamma R-\sinh\gamma R)}{(\mu-1)(\gamma R\cosh\gamma R-\sinh\gamma R)+(\gamma R)^2\sinh\gamma R},$$

where K is a constant of the cavity, μ is the complex intrinsic scalar permeability associated with a circularly polarized wave, and $\gamma=\omega(\mu\epsilon)^{\frac{1}{2}}$. Theoretical results are compared with measurements made on polycrystalline and single-crystal samples of ferrite. Good agreement is seen with regard to absence of size effects. A brief discussion is given of theories of the resonance line shape.

D6. Rigorous Theory of Single-Domain Ferromagnetic Particles. WILLIAM FULLER BROWN, JR., *Minnesota Mining and Manufacturing Company.*—Consider a prolate spheroid with a direction of easy magnetization along the polar axis; apply a large field H_0 along this axis, then decrease it. Uniform magnetization along H_0 satisfies the equilibrium condition, vanishing of the first variation of the free energy; the stability of the equilibrium depends on the sign of the second variation. As was shown earlier,[1] a sufficient condition for stability is that H_0 exceed a certain negative value. On further decrease, instability occurs at an H_0 determined by the smallest eigenvalue of a boundary-value problem. The mode of deviation is determined by the corresponding eigenfunction. It is uniform or nonuniform according as the radius is smaller or larger than $xJ_s^{-1}(C/N_b)^{\frac{1}{2}}$: J_s and C as in reference 1, N_b = transverse demagnetizing factor, $x=1.84$ for cylinder and 2.08 for sphere (zeros of $J_1'(x)$ and $j_1'(x)$, respectively). Except for the numerical factor, this agrees with an approximate formula of Kondorskii.[2]

[1] W. F. Brown, Jr., Revs. Modern Phys. **17**, 15 (1945).
[2] E. Kondorskii, Doklady Akad. Nauk S S S R **82**, 365 (1952).

D7. Effect of a Cavity in a Single-Domain Magnetic Particle. A. H. MORRISH, *University of Minnesota,* AND WILLIAM FULLER BROWN, JR., *Minnesota Mining and Manufacturing Company.*—We have investigated theoretically the suggestion[1] that cavities might contribute to the low coercive force of powders, as compared with predictions of single-domain-particle theory. With particle and cavity ellipsoidal, the magnetostatic energy can be evaluated by separation into three terms: the self-energy of the external poles; the self-energy of the internal; and the mutual energy of the two, calculated by regarding the internal as subject to the uniform field of the external. The coercive force follows by the Stoner-Wohlfarth method. We consider a prolate spheroidal particle containing a spheroidal cavity, with applied field along the particle axis, and with the cavity axis at angle Θ thereto. Cases in which the cavity decreases the coercive force include: $\Theta=\pi/2$; $\Theta=0$, cavity less eccentric than particle; $\Theta\gtrsim\pi/4$, cavity small and prolate; any Θ, cavity small and oblate.

[1] A. H. Morrish and S. P. Yu, J. Appl. Phys. **26**, 1049 (1955).

D8. Nuclear Quadrupole Coupling of B^{11} and Al^{27} in Ionic Crystals.* P. J. BRAY AND A. H. SILVER, *Brown University.*—The nmr of B^{11} has been observed in polycrystalline KBF_4 and $NaBH_4$ and the Al^{27} resonance in $AlCl_3\cdot6H_2O$ and $AlBr_3\cdot6H_2O$. A Pound-Watkins type spectrometer and a recorder were used to study the line shapes. The B^{11} resonance in orthorhombic[1] KBF_4 shows quadrupole splitting with the quadrupole coupling constant, eqQ, equal to 230 ± 30 kcps. As expected, in cubic[1] $NaBH_4$ the B^{11} nmr displays no evidence of quadrupole splitting. The Al^{27} nmr in rhombohedral[1,2] $AlCl_3\cdot6H_2O$ is split into five overlapping lines corresponding to $I=5/2$. The value of eqQ is 120 ± 20 kcps. In $AlBr_3\cdot6H_2O$, the Al^{27} nmr is an asymmetric pattern consisting of three lines. An analysis at 7.1 Mcps and 9.4 Mcps indicates that the

aluminum nuclei may have two nonequivalent lattice positions; one with $eqQ = 3.0 \pm 0.2$ Mcps and a second with a much smaller coupling constant.

* Research supported by the National Science Foundation and by the U. S. Atomic Energy Commission.
[1] Wyckoff, *Crystal Structures* (Interscience Publishers, Inc., New York, 1951).
[2] Andress and Carpenter, Z. Krist. **87A** 446 (1934).

D9. Nuclear Electric Quadrupole Coupling in Glasses.* A. H. SILVER AND P. J. BRAY, *Brown University*.—The B^{11} nmr has been observed in powdered vitreous B_2O_3, Pyrex and Corning 7070[1] glass using a Pound-Watkins-type recording spectrometer. The resonance line in each case is produced by the $m = -\frac{1}{2} \rightarrow \frac{1}{2}$ transition, and the shape shows the second-order broadening effect of nuclear quadrupole interaction.[2] Tentative values of the quadrupole coupling constant are

Material	% B_2O_3	eqQ (Mcps)
B_2O_3	100	2.9 ± 0.2
Pyrex	14[3]	1.6 ± 0.2
7070 glass	27[3]	1.6 ± 0.2

The presence of the B^{11} nmr in these glasses indicates that the majority of boron nuclei have very similar local environments in agreement with the role of B_2O_3 as a network former.[1] This should be contrasted with the failure to detect a Na^{23} nmr in soda-lime glass (20% Na_2O). The Na^{23} atoms are known[2] to occupy random positions in the silicon-oxygen network.

* Research supported by the U. S. Atomic Energy Commission.
[1] E. V. Condon, Am. J. Phys. **22**, 43 (1954).
[2] N. Bloembergen, "Defects in crystalline solids," Bristol Conference Report (1955).
[3] Warren and Biscoe, J. Am. Ceram. Soc. **21**, 259 (1938).

D10. Evidence for Association in NaCl:Mn Using Electron Resonance. G. D. WATKINS AND R. M. WALKER, *General Electric Research Laboratory*.—The electron resonance spectrum of manganese has been studied in a single crystal of NaCl:Mn (0.004%) up to a temperature of 450°C. At this temperature the spectrum contains only six hyperfine lines consistent with a cubic environment for the Mn^{++}. Near 200°C the spectrum is quite complex and indicates that very little manganese remains in cubic symmetry. The low-temperature spectrum has been studied *vs* crystal orientation and can be explained by two separate sets of crystalline field interactions indicating two discrete physical environments available to the manganese. One likely interpretation of these results is that these noncubic fields result from the presence of an associated Na^+ vacancy. The nearest and next-nearest available vacancy sites are consistent with the required symmetries. In addition, the lines are observed to broaden *vs* temperature, indicating a thermal reorientation of the complexes. The jump frequencies required are about those expected for a Na^+ vacancy. However, preliminary studies in the transition region between the low- and high-temperature spectra indicate a sharper transition than is predicted by theory.[1]

[1] A. B. Lidiard, Phys. Rev. **94**, 29 (1954).

D11. Paramagnetic Resonance Absorption in Irradiated Thallium Activated Potassium Chloride.* BERNARD SMALLER, CHARLES DELBECQ, AND PHILLIP YUSTER, *Argonne National Laboratory*.—The magnetic properties of the metastable state of the luminescence system KCl–Tl have been investigated using the paramagnetic resonance technique. The thallium activated alkali halide was irradiated at 80°K by γ or x rays to produce a sufficient number of metastable states to be observed. Examination of the spectra at 9000 Mcps revealed a seven-line structure corresponding to the Cl_2^- molecule ion. The structure appears similar to that of the V center reported by Kanzig[1] with a g value of 2.023 for $H \| (1,0,0)$ as expected for a trapped positive hole. Identification of the magnetic center with the luminescent center is suggested on the basis of the following evidence: (1) upon warming the crystal, the magnetic resonance spectra disappeared at the same temperature *ca* 200°K, as the glow peak in the thermoluminescence; (2) stimulation with infrared light destroyed both resonance spectra and thermoluminescence.

* Based on work performed under the auspices of the U. S. Atomic Energy Commission.
[1] Werner Kanzig, Phys. Rev. **99**, 1890 (1955).

FRIDAY MORNING AT 10:00

Social Sciences 122

(H. H. BARSCHALL presiding)

Reactions of Transmutation, I

E1. A Study of the Reaction Mechanism for (He^3,p) Reactions with Li^6, B^{10}, and C^{13}.† J. P. SCHIFFER,* T. W. BONNER, R. H. DAVIS, AND F. W. PROSSER, JR., *The Rice Institute*.—Excitation curves and angular distributions for five (He^3,p) reactions have been obtained with bombarding energies between one and five Mev. Since the initial and final states were of known spin and parity, the results give information on the reaction mechanisms involved. All the reactions studied showed resonances in the excitation curves indicating that they proceeded at least in part by way of a compound system. In one or possibly two cases, the angular distributions showed a strong assymmetry about 90° suggesting the admixture of some other reaction mechanism.

† Supported in part by U. S. Atomic Energy Commission.
* Now at Argonne National Laboratory, Lemont, Illinois.

E2. Study of Reactions $Li^6(n,\gamma)Li^7$ and $B^{10}(n,\gamma)B^{11}$. G. A. BARTHOLOMEW AND P. J. CAMPION, *Chalk River Laboratories*.—In $Li^6(n,\gamma)Li^7$ γ rays at 7.26 ± 0.03 and 6.78 ± 0.05 Mev are observed. These energies correspond to transitions from the capturing state to the ground state and first excited state in Li^7. The intensity of the 6.78 Mev γ ray is 0.75 ± 0.20 times that of the 7.26 Mev γ ray. In $B^{10}(n,\gamma)B^{11}$ γ rays are observed at 11.43 ± 0.04, 8.91 ± 0.03, 6.98 ± 0.03, and 4.47 ± 0.02 Mev with relative intensities of 0.01, 0.07, 0.2, and 1.0, respectively. In addition γ rays at 6.76 ± 0.04 and 4.73 ± 0.03 Mev also appear to be emitted in this reaction, though the identification is less certain. From the foregoing data and the results of a separate experiment in which the strengths of these γ rays are compared to those of γ rays of known absolute intensity from sources of known cross section, estimates of the thermal radiative capture cross sections in Li^6 and B^{10} may be obtained. Neglecting possible contributions from $(n,\gamma\alpha)$ transitions, the total observed radiative capture cross sections are 23 ± 8 mb for Li^6 and 450 ± 200 mb for B^{10}.

E3. Energy Levels of Be^8.* J. R. CAMERON, *University of Pittsburgh*.—A search was made for energy levels in Be^8 by

means of the reactions $Be^9(p,d)Be^8$ and $Be^9(d,t)Be^8$. The first reaction was studied at θ_{lab} 13.5° and 23° using 7.4 Mev protons on a thin Be target. The ground state and broad 2.9-Mev level were the only Be^8 levels observed in the region from 0- to 6.5-Mev excitation. Using 14.8 Mev deuterons, the second reaction was studied at $\theta_{lab}=15°$ in the region of 7.1- to 15.4-Mev excitation in Be^9. No Be^8 levels were observed. If any levels were present, they were weak and/or broad.

* Work done at the Sarah Mellon Scaife Radiation Laboratory and assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

E4. Angular Distributions of Protons from Deuteron Bombardment of Be^9 and B^{10}.* B. Zeidman and J. M. Fowler, *Washington University.*—Thin targets of Be^9 and B^{10} were bombarded by 10-Mev deuterons and the angular distributions of protons from the ground and first excited states of Be^{10} and B^{11} were measured from 10° to 160° with a proportional counter-scintillator telescope. The angular distributions for the ground and first excited states of Be^{10} and the ground state of B^{11} show good agreement with the theoretical Butler curves for $l_n=1$ and $r_0=5.2\times10^{-13}$ cm at the forward angles. The angular distribution for the ground state of Be^{10} has an essentially isotropic non-Butler contribution at the backward angles, while the angular distribution for the first excited state shows an anomalous peak at 110° and a nonisotropic background at the backward angles. The B^{11} ground-state distribution has a non-Butler contribution at higher angles while the B^{11} first excited state is poorly fitted by the Butler curve at all angles. The relative total cross sections were $\sigma_g/\sigma_e\approx0.5$ for $Be^9(d,p)Be^{10}$ and $\sigma_g/\sigma_e\approx6$ for $B^{10}(d,p)B^{11}$. The ratios of the relative differential cross sections at the peak of the "stripping curves" were $d\sigma_g/d\sigma_e\approx0.5$ for $Be^9(d,p)Be^{10}$ and $d\sigma_g/d\sigma_e\approx19$ for $B^{10}(d,p)B^{11}$.

* Supported in part by the U. S. Air Force through the Office of Scientific Research of the Air Force Research and Development Command.

E5. Differential Cross Sections for the $Be^9(He^3,p)B^{11}$, $C^{13}(He^3,p)N^{15}$, and $C^{13}(He^3,\alpha)C^{12}$ Reactions. E. A. Wolicki, H. D. Holmgren, R. L. Johnston, and E. H. Geer, *Naval Research Laboratory.*—Differential cross sections have been measured as a function of bombarding energy at 50-kev intervals from 2.0 to 3.8 Mev at 0°, 30°, 60°, 90°, 120°, and 150° in the laboratory system. Results have been obtained for the ground state and first excited state proton groups from the $Be^9(He^3,p)B^{11}$ reaction. No resonances were observed. Similar results have been reported for this reaction in the energy range between 1.0 and 2.7 Mev by Almqvist *et al.*[1] For the $C^{13}(He^3,p)N^{15}$ and $C^{13}(He^3,\alpha)C^{12}$ reactions, measurements were made for the ground-state groups. Both reactions showed a broad weak resonance in the yield curves at approximately 3.6 Mev. In general, the angular distributions for all three reactions are not symmetric about 90° and show a gradual change throughout the energy range studied becoming more complex with increasing energy. It appears unlikely that this behavior can be explained solely in terms of the compound nucleus model.

[1] Almqvist, Bromley, Gove, Litherland, and Paul, Bull. Am. Phys. Soc. Ser. II, 1, 195 (1956).

E6. Angular Distributions of the Ground-State Neutrons from $B^{11}(dn)C^{12}$. Oakes Ames, George E. Owen, and C. D. Swartz, *The John Hopkins University.*—The angular distributions of neutrons to the ground state of C^{12} produced in the $B^{11}(dn)C^{12}$ reaction have been measured in the deuteron energy range of 0.60 to 1.15 Mev. A stilbene crystal was used as the detector. The distribution at 0.6 Mev shows a strong forward throw, while that at 1.15 Mev is more nearly isotropic. Deuteron and heavy particle stripping theory are sufficient to account for the angular distributions observed.

E7. The $C^{12}(n,p)B^{12}$ Reaction for 17.3-Mev Neutrons. W. E. Kreger, H. H. Bolotin, and E. A. Edelsack, *U. S. Naval Radiological Defense Laboratory.*—The cross section for the $C^{12}(n,p)B^{12}$ reaction has been measured using the 17.3 Mev neutrons produced by 1.5-Mev Van de Graaff deuterons incident on a zirconium-tritium target. The deuteron beam was pulsed, providing a pulsed neutron beam at a carbon target. The desired reaction cross section was measured by detecting the 4.45-Mev gamma radiation given off when the radioactive B^{12} nuclei beta decay to C^{12*} and C^{12}. Since the B^{12} half-life is approximately 22 msec, the beam pulse length used was 20 msec, and a repetition rate of 10 pulses per second allowed a measurement of the decay gamma rays during the 80-msec beam off time. A system of gated scalers was used with a 1-in. diam by 1-in. NaI(Tl) scintillation detector system for this measurement. The incident neutron flux was measured with an anthracene crystal neutron detector whose efficiency had been determined by comparing its response with the measured number of alpha particles given off in the $T^2(d,n)He^4$ reaction. The cross-section value is 29 ± 23 mb, the large error being due to a large background of longer lived activities which could not be eliminated.

E8. Differential Cross Sections for the $C^{13}(He^3,p)N^{14}$ Reaction as a Function of Energy. H. D. Holmgren, E. H. Geer, R. L. Johnston, and E. A. Wolicki, *Naval Research Laboratory.*—The differential cross sections for the $C^{13}(He^3,p)N^{14}$ reactions which leave N^{14} in the ground and first excited states have been measured for six angles (7, 30, 60, 90, 120, and 150 degrees) at 50-kev energy intervals extending from 2.00 to 3.80 Mev. The yields of the ground-state proton group exhibit strong resonances for all angles at bombarding energies of 2.95 and 3.6 Mev and rather weak indications of resonances for some angles at 2.12 and 2.5 Mev. The yields at all angles except 60 degrees for the first excited state group show a strong resonance near 2.45 Mev. In addition, the yields at 60 and 90 degrees for this group indicate the presence of resonances at 2.7 and 2.95 Mev. The widths of all these resonances are of the order of 200 kev, except the resonance that appears in the ground-state group yields at 2.12 Mev which is less than 100 kev. The angular distributions change rapidly in the region of these resonances. The presence of these resonances suggest that the compound nucleus process plays an important part in this reaction for the region of bombarding energy investigated. The resonances at 2.12 and 2.45 Mev are in agreement with the work of Bromley *et al.*[1]

[1] Bromley, Gove, Litherland, Paul, and Almquist, Bull. Am. Phys. Soc. Ser. II, 1, 195 (1956).

E9. The Mass of C^{15} and the Excitation Energy of a Low-Lying Excited State.* P. G. Murphy, *University of Chicago.*—Two long-range proton groups produced when a beryllium target is bombarded with 2-Mev Li^7 ions arise from the reaction $Be^9(Li^7,p)C^{15}$. Their ranges have been studied, using the protons from $Li^6(Li^7,p)B^{12}$, where the masses of all nuclei involved are well known, and energies can be reliably calculated. The more energetic group has 9.48 ± 0.05-Mev kinetic energy, and under our bombardment conditions is half as abundant as the 8.82 ± 0.05-Mev group. No groups of higher energy protons have been observed, the limiting intensity observable being estimated as 1% of the groups in question. It is judged highly probable that the residual nucleus from the more energetic proton group is C^{15} in its ground state; its $M-A$ value is then 14.35 ± 0.05 Mev, and its physical atomic weight 15.01541 ±0.00005, agreeing with that reported by Douglas, Broer, and Chiba.[1] The excited state of C^{15}, not previously reported, has 0.70 ± 0.05 Mev excitation energy.

* Work supported in part by the U. S. Atomic Energy Commission.
[1] Douglas, Broer ,and Chiba, Phys. Rev. 100, 1253 (1955).

E10. (d,p) Reactions from N^{14}, N^{15}, and He^4.* E. K. Warburton and J. N. McGruer, *University of Pittsburgh* (intro-

duced by R. S. Bender).—14.8-Mev deuterons were incident upon a nitrogen gas target (enriched in N^{15}). Butler-type stripping analyses and reduced width calculations were made for proton groups leading to known levels in N^{15} and N^{16}, yielding values:

N^{15} State (Mev):	Ground	6.328	7.575	8.316	8.571
$l_n =$	1	1	0(?), 2	0	0, 2
$(2J+1)\Theta^2 =$	0.097	0.030	0.06(?), 0.40	0.47	0.018, 0.031

N^{16} State (Mev):	Ground	0.12	0.30	0.40
$l_n =$	2	0	2	0
$(2J+1)\Theta^2 =$	0.27	0.19	0.33	0.54

The results of the stripping analyses were combined with theoretical predictions to assign most probable J values of 2, 0, 3, and 1 to the N^{16} levels at 0, 0.12, 0.30, and 0.40 Mev, respectively. Previously unreported levels in N^{16} were found at 3.98, 4.80, and 5.25 Mev and possibly at 3.53 and 5.01 Mev. Using a helium target, a half-width $\Delta Q = 0.55 \pm 0.30$ Mev was measured for the He^5 ground state. Assuming an $l_n = 1$ transition, cross-section measurements at two angles gave $\Theta^2 = 0.05$ for the $He^4(d,p)He^5$ ground-state reaction.

* Work done at the Sarah Mellon Scaife Radiation Laboratory and assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

E11. $N^{14}(d,n)O^{15}$ and $N^{15}(d,n)O^{16}$ Reactions.* K. W. Jones, J. L. Weil, T. H. Kruse, J. A. Baicker, and L. J. Lidofsky, *Columbia University.*—The excitation functions of $N^{14}(d,n)O^{15}$ and $N^{15}(d,n)O^{16}$ have been measured in the forward direction for bombarding energies of 2 Mev to 4.5 Mev and 0.5 Mev to 5.0 Mev, respectively. Gas targets of N^{14}(99.9%) and N^{15}(74%) were used. The detector for the $N^{14}(d,n)O^{15}$ reaction was a single disk of plastic scintillator 2.54 cm in diameter and 0.29 cm thick, while for the $N^{15}(d,n)O^{16}$ reaction two cylinders of plastic scintillator 0.63 cm by 0.63 cm separated by 0.16 cm of copper were used. In both cases the discriminator bias was set high enough so that only ground-state neutrons were detected. Both reactions showed resonance effects. Absolute cross sections were estimated using calculated counter efficiencies. In the case of the $N^{14}(d,n)O^{15}$ reaction the method was checked using neutrons of equal energy from the $D(d,n)He^3$ reaction. Preliminary values for the maximum laboratory cross sections observed at 0° are 4 mb/sterad at $E_D = 2.3$ Mev for $N^{14}(d,n)O^{15}$ and 6 mb/sterad at $E_D = 1.8$ Mev for $N^{15}(d,n)O^{16}$. Angular distributions were taken at a number of energies for each reaction and show strong maxima at small angles.

* This work was partially supported by the U. S. Atomic Energy Commission.

Friday Afternoon at 2:30

Social Sciences 122

(J. J. Livingood presiding)

Reactions of Transmutation, II

G1. $N^{14}(\alpha,\alpha)N^{14}$ and $N^{14}(\alpha,p)O^{17}$ Differential Cross Sections.* D. F. Herring, Ren Chiba, B. R. Gasten, and H. T. Richards, *University of Wisconsin.*—Differential cross sections for the $N^{14}(\alpha,\alpha)N^{14}$ and $N^{14}(\alpha,p)O^{17}$ ground-state reactions have been measured for bombarding energies from 2 to 3.8 Mev at angles of 90°, 125.3°, 140.8°, and 171.0° in the $N^{14}(\alpha,\alpha)N^{14}$ center-of-mass system. Differentially pumped nitrogen was used as a target. $N^{14}(\alpha,\alpha)N^{14}$ resonances were found at approximately $E_\alpha = 2.34$, 2.76, 2.86, 2.90, 3.04, 3.14, 3.56, and 3.69 Mev. The levels corresponding to $E_\alpha = 2.86$-, 3.04-, and 3.69-Mev decay via proton emission to the O^{17} ground state. The resonances at 2.34, 2.76, 2.86, and 3.56 have $\Gamma_{1ab} \leq 5$ kev. The resonances at 3.04 and 3.69 have approximate Γ_{1ab} of 105 kev and 53 kev, respectively. Work is continuing at lower energies and on the $N^{14}(\alpha,p)O^{17}$ first excited state reactions.

* Work supported by the U. S. Atomic Energy Commission and by the Graduate School from funds supplied by the Wisconsin Alumni Research Foundation.

G2. Total Cross Section of O^{16} and the $O^{16}(n,\alpha)$ Reaction Cross Section.* R. B. Walton, J. D. Clement, and F. Borelli,† *University of Wisconsin.*—The total cross section of O^{16} was measured for neutron energies from 3.4 to 4.4 Mev. A Hornyak scintillator was used to detect neutrons produced by bombarding a deuterium gas target with deuterons. The cross section was determined by transmission measurements using SnO_2 and Sn samples. Resonances were observed at neutron energies of 3.75, 4.00, 4.17, 4.31, and 4.43 Mev. Using neutrons from the $D-D$ reaction, the $O^{16}(n,\alpha)$ reaction cross section was measured for neutron energies from 4.0 to 5.2 Mev. The oxygen disintegrations were detected with a cylindrical proportional counter filled with 1.41 atmos of CO_2. The neutron flux was measured with a long counter calibrated with a Ra−Be source. Resonances were observed at neutron energies of 4.02, 4.16, 4.28, 4.45, 4.51, 4.58, 4.62, 4.84, 5.03, and 5.11 Mev. These correspond to energy levels in the compound nucleus O^{17} observed in the O^{16} total cross section and the $C^{13}(\alpha,n)$ reaction cross section. The $O^{16}(n,\alpha)$ cross section varies from about 20 mb to 180 mb. A comparison of the cross section for this reaction with that for the inverse reaction $C^{13}(\alpha,n)$ on the basis of the principle of detailed balancing shows satisfactory agreement.

* Work supported by the U. S. Atomic Energy Commission and by the Graduate School from funds supplied by the Wisconsin Alumni Research Foundation.

† On leave from Institute "Boris Kidrich," Yugoslavia.

G3. Angular Distributions of Protons from $O^{17}(d,p)O^{18}$.† O. M. Bilaniuk, *University of Michigan.*—Elliot and Flowers[1] and Redlich[2] predict the first four states in O^{18} to have spins and parities 0+, 2+, 0+, 4+, respectively. To test these predictions LiOH with oxygen enriched to 0.75% in O^{17} has been used as a target for the 7.8-Mev deuteron beam of the Michigan cyclotron to study the angular distributions of protons from $O^{17}(d,p)O^{18}$ corresponding to the ground state, the 1.98 Mev and the 3.55 Mev levels of O^{18}. The protons after being analyzed by a high-resolution analyzing magnet[3] have been recorded in Kodak 100μ NTB emulsions. Comparison with Butler's theoretical curves leads to the tentative results listed below. Relative intensities of proton groups indicate that underlined final spins are to be preferred, in accord with theory.

	Q value	l_n	Final spin	Final parity
$O^{17}(d,p)O_0^{18}$	5.821	2	0,1,4,5	Even
$O^{17}(d,p)O_1^{18}$	3.835	0,2	2,3	Even
$O^{17}(d,p)O_2^{18}$	2.266	2	0,1,4,5	Even

† Supported by the U. S. Atomic Energy Commission and the Michigan Memorial Phoenix Project.

[1] J. P. Elliot and B. H. Flowers, Proc. Roy. Soc. (London) **A229**, 536 (1955).

[2] M. G. Redlich, Phys. Rev. **99**, 1427 (1955); **95**, 448 (1954).

[3] Bach, Childs, Hockney, Hough, and Parkinson, Rev. Sci. Instr. **27**, 516 (1956).

G4. Excitation Function of $O^{18}(p,n)F^{18}$ Reaction to 40 Mev.† YUNG SU TSAI, *University of Minnesota.*—Ten-Mev and 40-Mev proton beams from the linear accelerator were used to bombard stacked Mylar ($C_{10}(H_2O)_4$) foils of ¼-mil and 3-mil thickness, respectively. Activity resulting from F^{18} was measured by a G.M. counter whose efficiency was calibrated by a β–γ coincidence method. Many peaks were observed in the 10-Mev experiment. The resolution of the experiment was limited mainly by the stopping power of ¼-mil Mylar, which is about 100 kev at 3 Mev, 60 kev at 6.5 Mev, and 40 kev at 10 Mev. In 40-Mev data all peaks were averaged out by using thicker foils (3-mil Mylar). The maximum cross section occurs at (5.6±.6) Mev with $\sigma = (425 \pm 40)$ mb. The cross sections then fall off with increasing energy: at energies of 10, 15, 20, 25, 30, and 40 Mev. The respective cross sections are (270 ±30), (150±20), (75±10), (40±10), (30±8), and (27±7) mb. From the position of the maximum cross section, $O^{18}(p,d)O^{17}$ is probably the main competing reaction rather than $O^{18}(p,2n)F^{17}$. The cross sections at higher energies are considered to be the result of the direct interaction process.

† Supported in part by the U. S. Atomic Energy Commission.

G5. Time-of-Flight Measurements on Neutrons from the Reaction $Mn^{55}(p,n)Fe^{55}$.† ROBERT E. HOLLAND AND RALPH C. EHLERT, *Argonne National Laboratory.*—Neutron groups from $Mn^{55}(p,n)Fe^{55}$ were studied by measuring their time of flight. The proton beam of the Argonne electrostatic generator was chopped with a 3.5-Mcps sine wave to get 2 mμsec pulses. Neutrons from the reaction were detected in a plastic scintillator 36 in. from the target, and the resulting pulses were fed into a time-to-pulse-height converter of Los Alamos design.[1] With a proton energy of 3.26 Mev, neutrons corresponding to formation of Fe^{55} in the ground state and in the first two excited states were measured. The results are in general agreement with previous work[2] on this reaction in which nuclear plates were used.

† Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] Weber, Johnstone, and Cranberg, Rev. Sci. Instr. **27**, 166 (1956).
[2] P. H. Stelson and W. M. Preston, Phys. Rev. **82**, 655 (1951).

G6. Resonant Detection of Neutron Energy Groups.* F. P. MOORING AND L. L. LEE, JR., *Argonne National Laboratory.*—A technique for measuring excitation energies of residual nuclei in (p,n) and similar reactions has been developed. Neutrons from a reaction are allowed to strike a resonant scatterer, and the ratio of the scattered to the transmitted neutron flux is measured as a function of incident proton energy. Whenever the energy of a neutron group passes through the resonance energy of the scatterer, a fluctuation in the ratio occurs. From the resonance energy and the incident proton energy, the Q value for the production of the neutron energy group, and hence the excitation energy of the the residual nucleus, is easily obtained. To test the method the reaction, $Mn^{55}(p,n)Fe^{55}$, has been studied. Lithium, which has only one scattering resonance, was used as the resonant detector.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

G7. Neutron Thresholds in the $Co^{59}(p,n)Ni^{59}$ Reaction. J. W. BUTLER, K. L. DUNNING, AND R. O. BONDELID, *U. S. Naval Research Laboratory.*—The reaction $Co^{59}(p,n)Ni^{59}$ has been investigated with a neutron threshold technique in order to find energy levels in Ni^{59}. Targets of metallic cobalt, of the order of a few kev thick to the incident protons, were bombarded with the proton beam of the NRL 5-Mv Van de Graaff accelerator. The ground-state threshold was measured to be 1.889±0.004 Mev. Excited state thresholds were found at bombarding energies of 2.237±0.005, 2.337±0.005, 3.13±0.01, 3.256±0.010, 3.710±0.012, 3.89±0.02, 4.08 ±0.02, 4.48±0.02, and 4.60±0.02 Mev. These correspond to excited states in Ni^{59} at 0.343±0.004, 0.441±0.004, 1.22 ±0.01, 1.343±0.010, 1.790±0.012, 1.96±0.02, 2.15±0.02 2.55±0.02, and 2.66±0.02 Mev, respectively. On the basis of this level scheme we have made isotopic assignments of the gamma rays resulting from thermal neutron capture by natural nickel reported by Kinsey and Bartholomew.[1]

[1] B. B. Kinsey and G. A. Bartholomew, Phys. Rev. **89**, 375 (1953).

G8. Ratio of the (p,n) to the (p,p') Reaction for Sr^{87}.† S. W. CHEN AND N. M. HINTZ, *University of Minnesota.*—To test the statistical theory[1] of nuclear reactions it is desirable to measure the cross sections for the simplest possible reactions; e.g., (p,n), (p,p'), (p,γ), etc. By bombarding a stable nucleus which has an isomeric state it is possible to measure the ratio $\sigma(p,n)$ to $\sigma(p,p')$ without knowing the target thickness, proton charge collected, or absolute detection efficiency. In this experiment, the (p,p') reaction was measured by detecting the 0.390-Mev gamma ray from the decay of the 2.8 hr, Sr^{87m}. The (p,n) reaction was measured by detecting the same 0.390-Mev gamma ray following the decay of Y^{87}. The ratio $\sigma(p,n)/\sigma(p,p')$ was measured from $E_p = 5.6$ to 9.5 Mev. The data are consistent with the statistical theory only if the value of a, in the level density formula $\omega(E) = C \exp[2(aE)^{\frac{1}{2}}]$, is taken to be about 2. This is then in agreement with other excitation function measurements[2] which indicate a value of a much lower than that obtained from the energy spectrum of emitted particles or from slow neutron resonance measurements.

† Supported in part by the U. S. Atomic Energy Commission.
[1] J. M. Blatt and V. F. Weisskopf, *Theoretical Nuclear Physics* (John Wiley and Sons, Inc., New York), Chap. VIII, Sec. 6.
[2] See, for example, Karl G. Porges, Phys. Rev. **101**, 225 (1956).

G9. Energy Dependence of η for Uranium-233 in the Region 0.1 to 4.0 ev.* E. H. MAGLEBY, J. R. SMITH, J. E. EVANS, AND M. S. MOORE, *Phillips Petroleum Company.*—Measurements have been made of the energy dependence of η, the number of fission neutrons emitted per neutron absorbed, for uranium-233 in the energy region 0.1 to 4.0 ev. The uranium-233 sample had an effective thickness to the beam of 6.9 g/cm². This metal sample was obtained on loan from the British Atomic Energy Research Establishment at Harwell. The Materials Testing Reactor crystal spectrometer experimental arrangement is as previously described[1] with the exception that a long counter has been used as a fission neutron detector in addition to the Hornyak button. The MTR data are normalized to the Brookhaven slow chopper results. Dips are observed in the vicinity of each of the three known resonances below 4 ev. Near the 2.3-ev resonance, η dips nearly to unity.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] J. R. Smith and E. H. Magleby, Phys. Rev. **100**, 1266(A) (1955).

G10. Uranium-233 Resonance Parameters for Neutron Energies below 4.0 ev.* M. S. MOORE, L. G. MILLER, AND C. W. REICH, *Phillips Petroleum Company.*—The previously reported[1] high resolution (0.08 μ sec/m) fission cross-section measurements have been extended with the MTR crystal spectrometer to neutron energies of 4.0 ev. With an exact multilevel dispersion formula,[2] including Doppler corrections, these data have been fitted to within the experimental uncertainty. The vest fit was obtained by requiring full interference of all levels in the 0–4 ev energy region. Preliminary parameters are shown below. In addition, it was necessary to consider interference effects from resonances outside this region. These have been represented by the additional resonances tabulated, although this representation is not

unique. The parameters shown are consistent with total cross-section and η measurements.

E_0(exp)(ev)	···	1.785	2.30	3.63	···	4.5	4.7
E_0(theory)(ev)	0.10	1.81	2.325	3.65	−5.0	4.5	4.7
$g\Gamma_n^0(10^{-3}$ev)	1.67×10^{-3}	0.150	0.061	0.039	3.24	0.015	0.010
Γ_f(ev)	1.00	0.254	0.062	0.157	0.36	0.18	0.13
Γ_γ(ev)	0.040	0.045	0.040	0.040	0.041	0.040	0.040

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] L. G. Miller and J. E. Evans, Bull. Am. Phys. Soc. Ser. II, 1, 247 (1956).
[2] E. P. Wigner and L. Eisenbud, Phys. Rev. 72, 29 (1947).

G11. Ionization Defect for Fission Fragments.* N. G. UTTERBACK, *Iowa State College* (introduced by C. L. Hammer).—The ratio of fission fragment ionization yield to alpha-particle ionization yield has been measured in argon, helium, and helium plus three-tenths percent argon with a parallel-plate gridded ionization chamber. Energies found for the most probable light and heavy fragments by multiplying these ratios by the alpha energy are, respectively: 93.6, 96.2, 97.8, 60.8, 65.0, and 65.9 Mev. Natural uranium was fissioned by $D-D$ neutrons from the Iowa State College kevatron. Saturation and rise-time effects were studied in detail. The energy difference between argon and helium agrees with that predicted on the basis of atomic collisions by Knipp and Ling.[1] The addition of sufficient argon to discharge the metastable atoms in helium appears to be a convenient method for studying the relative amount of energy absorbed as excitation in the stopping of the fragments and the alphas.

* Work performed in the Ames Laboratory of the U. S. Atomic Energy Commission.
[1] J. K. Knipp and R. C. Ling, Phys. Rev. 82, 30 (1951).

G12. Recoil Studies of High-Energy Fission of Bismuth and Tantalum. NORBERT T. PORILE* AND NATHAN SUGARMAN, *University of Chicago.*—Ranges of several recoil fragments, ranging from Mn^{56} to $Ba^{129,133m}$, in the 450-Mev proton bombardment of bismuth, and from Sc^{47} to Ba^{129} in similar bombardments of tantalum, have been measured. The kinetic energies of these fragments were calculated from the measured ranges and other reported range-energy data, and are in agreement with those expected from a high-energy fission process. The ratios of recoiling fragments projected along the direction of the incoming beam to those projected perpendicular to the beam were measured. The results show that the fragments are emitted anisotropically. The fragments from bismuth are emitted preferentially along the direction of the proton beam, and if an angular distribution of the form "$a+b\cos^2\theta$" is assumed, then b/a is about 0.1 in all cases. The fragments from tantalum are emitted preferentially perpendicular to the proton beam, and if the angular distribution is assumed to be "$a+b\sin^2\theta$," then b/a is about 0.3 for Sc^{47} and Ba^{129} and is less than 0.1 for the other fragments. The deposition energy in the target nuclei was obtained from the recoil data and subsidiary calculations involving conservation of energy and momentum. It is lowest for symmetric fission, ranging from 250 to 330 Mev for bismuth, and from 310 to 370 Mev for tantalum.

* National Science Foundation Predoctoral Fellow.

G13. Interference between Fission Resonances.* R. E. COTÉ AND L. M. BOLLINGER, *Argonne National Laboratory.*—The results obtained in measurements of the total and fission cross sections, σ_t and σ_f and of ν for slow neutrons on Pu^{239} were given in previous reports.[1] These results provide convincing evidence that the fission component of neutron resonances does not obey the single level Breit-Wigner shape. For the isolated pair of levels at 10.9 and 11.9 ev, in particular, there is a large excess fission cross section between the resonances and no corresponding departure from single level shapes for the radiative capture cross section. These data are interpreted in terms of the theoretically predicted interference between levels and are quantitatively fitted by assuming that there is a single exit channel in the fission reaction. Other asymmetries in the data are also discussed.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] Coté, Bollinger, LeBlanc, and Thomas, Bull. Am. Phys. Soc. Ser. II, 1, 187 (1956).

FRIDAY AFTERNOON AT 2:30

Eckhart 133

(R. S. MULLIKEN presiding)

Symposium of the Division of Chemical Physics
Recent Advances in Molecular Spectroscopy

H1. Slightly-Hindered Rotation of Molecules and Ions in Crystals. D. F. HORNIG, *Brown University.* (40 min.)

H2. High-Resolution Spectroscopy in the Vacuum Ultraviolet. P. G. WILKINSON, *University of Chicago.* (40 min.)

H3. High-Resolution Spectroscopy in the Infrared. E. K. PLYLER, *National Bureau of Standards.* (40 min.)

H4. Spectra and Structure of Coordination Compounds. J. W. RICHARDSON, *Iowa State College.* (40 min.)

FRIDAY AFTERNOON AT 2:30

Cobb 110

(T. B. NOVEY presiding)

Radioactive Nuclei

J1. Mass and Half-Life of B^8. K. L. DUNNING, J. W. BUTLER, AND R. O. BONDELID, *Naval Research Laboratory.*—Targets of Li^6 (metallic and fluoride) were bombarded with singly charged He^3 ions in the energy range 2.9 to 4.5 Mev from the Naval Research Laboratory 5-Mv Van de Graaff accelerator. The ground-state threshold for the reaction $Li^6(He^3,n)B^8$

was determined by observing the neutrons and also determined by observing the positron decay of B^8. Both methods gave the value 2.966 ± 0.009 Mev. This threshold energy corresponds to a Q value of -1.976 ± 0.006 Mev, a mass of 8.02716 ± 0.00001 for B^8, and a Q value of $+136$ kev for the Be^7 proton capture reaction. These data are based on Wapstra's mass tables.[1] The half-life of B^8, determined by simultaneously photographing the positron scaler and a 60-cy scaler with a motion picture camera, was found to be 0.78 ± 0.01 sec.

[1] A. H. Wapstra, Physica **21**, 367 (1955).

J2. Proton Bombardment of Beryllium at 2.56 Mev.* JOSEPH STOLTZFUS, JOSEPH FRIICHTENICHT, AND EDWARD B. NELSON, *State University of Iowa*.—The gamma angular distribution and the alpha-gamma angular correlation from the disintegration of B^{10} with an excitation energy of 8.89 Mev have been examined. The B^{10} was formed from Be^9 by proton bombardment and decayed by short range alpha emission to the second excited state of Li^6 at 3.58 Mev which decayed to the ground state by gamma emission. Scintillation detectors with a 4-in. long NaI(*Th*) crystal for gamma and a thin KI(*Th*) crystal for particles were used. Alphas were separated from the large elastically scattered proton background by pulse-height analysis. The gamma distribution was isotropic with respect to the incident beam, which is consistent with a $J=0+$assignment to the Li^6 level, already suggested by other evidence. The alpha-gamma correlation was measured at four angles in a plane including the beam and was isotropic within the 4% statistical uncertainty and is also consistent with the $J=0+$assignment. A measurement of the correlation in the plane normal to the incident beam is in progress.

* Supported in part by the U. S. Atomic Energy Commission.

J3. β-Decay Lifetimes of B^{13} and B^{12}.† E. NORBECK, JR., *University of Chicago*.—It has been shown[1] that one of the nuclear reactions occurring when a Li^7 target is bombarded with a 2-Mev Li^7 beam is $Li^7(Li^7,p)B^{13}$, with $Q=5.97\pm0.05$ Mev. Measurement of the β life of the B^{13} is complicated by the β activity of B^{12}, produced from $Li^7(Li^7,d)B^{12}$, and about three times as abundant as B^{13} under our conditions. The maximum energy available for β decay is 13.37 Mev for B^{12}; 13.43 Mev for B^{13}. Cook, of this Institute, has recently made a careful determination of $T_{\frac{1}{2}}$ for B^{12} from $C^{13}(\gamma,p)B^{12}$ and obtained $(18\pm1.5)\times10^{-3}$ sec; we have made an independent measurement using $B^{11}(d,p)B^{12}$ and found $(18.5\pm1)\times10^{-3}$ sec. The high-energy β radiation from Li^7-Li^7 has been examined with a system of electronic delays and gates; if an 18.5 msec activity is subtracted off, a longer lived component of 35 ± 15 msec remains, which we are ascribing to B^{13}. The prediction for an allowed odd-A transition would be in the range 35 to 1200 msec. Delayed neutrons have been searched for using a BF_3 counter, but none have been observed with a delay longer than expected due to slowing down before capture.

† Work supported in part by the U. S. Atomic Energy Commission.
[1] Allison, Murphy, and Norbeck, Phys. Rev. **102**, 1882 (1956).

J4. Lifetime of the First Excited State in Na^{23}.† R. W. KRONE, A. EVERETT, AND S. S. HANNA, *Argonne National Laboratory*.—Excited Na^{23} nuclei, $E_{ex}=0.44$ Mev, were produced by inelastic scattering of protons or alpha particles. In the reaction, $Na^{23}(p,p')Na^{23*}(\gamma)Na^{23}$, at the resonance $E_p=1.288$ Mev, Na^{23*} nuclei are projected, with velocities between 0.6 and 1.7×10^8 cm/sec, into a forward cone of $\theta<30°$. The radiation emitted by the excited nuclei was observed with a sodium iodide scintillator mounted first at 0° and then at 150° with respect to the proton beam. Electronic stability and magnetic drifts were investigated frequently during the measurements with suitable radioactive sources. The Doppler energy shift produced by this change of angle was measured for Na^{23} nuclei traveling in various media: vacuum, xenon gas, sodium chloride (the target material itself), and tantalum. The measured shift of about 0.6% is eliminated when the Na^{23} nuclei are stopped in tantalum, indicating a lifetime in the range 10^{-12} to 10^{-13} sec.

† Work performed under the auspices of the U. S. Atomic Energy Commission.

J5. Decay of Mo^{101} (14.6 min).* D. W. MARTIN AND S. B. BURSON, *Argonne National Laboratory*, AND J. M. CORK, *University of Michigan*.—The radiations emitted in the decay of 14.6-min Mo^{101} have been studied with the Argonne 256-channel coincidence scintillation spectrometer and with magnetic spectrographs. Ten major gamma rays of 0.080, 0.191, 0.510, 0.590, 0.704, 0.890, 1.024, 1.18, 1.56, and 2.08 Mev can be resolved in the normal spectrum. In coincidence experiments, evidence is obtained for at least twelve additional weaker transitions of 0.193, 0.300, 0.40, 0.51, 0.70, 0.84, 0.95, 1.14, 1.28, 1.38, 1.46, and 1.66 Mev. At least six distinct beta components of about 2.2, 1.6, 1.2, 0.8, 0.7, and 0.6 Mev can be discerned in beta-gamma coincidence experiments. The beta component of highest energy is in coincidence with the 0.590-Mev gamma ray. The strong 0.191-Mev gamma transition is not in prompt coincidence with beta rays; the half-life of the upper state has been determined to be about 9.1×10^{-4} sec. The K-conversion coefficient of this transition is 0.30 ± 0.06. The probable character is therefore $M2$ or $E3$, with no possibility that it can be $M4$. A decay scheme is proposed that is compatible with all the many gamma-gamma and beta-gamma coincidences observed and with the estimated intensities of all components. The scheme involves eleven excited states of Tc^{101} at 0.191, 0.510, 0.590, 0.70, 0.84, 0.89, 1.21, 1.59, 1.98, 2.08, and 2.16 Mev. The ground state is probably $g_{9/2}$.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

J6. Decay of Sb^{124}.† E. P. TOMLINSON, *Princeton University*.—By magnetic spectrometer measurements at 0.3% resolution of the β spectrum of Sb^{124} we have observed K- and L-conversion electrons from Te^{124} transitions with energies of 602, 645, 722, and 1690 kev and K-conversion electrons from transitions of 708, 713, and 2090 kev. Search for other transitions consistent with level schemes derived from the above have given positive suggestion only for a transition of 789 kev. Survey of the entire spectrum above 10 kev for additional lines revealed none belonging to Sb^{124}. From the transition energies above and triple coincidence data recently reported,[1] states in Te^{124} excited by the decay of Sb^{124} are established at energies of 602, 1247, 1324, 2292, and 2692 kev. There must also be at least one state between 1950 and 2050 kev. Available evidence suggests strongly but without positive proof that two states are excited at 1960 and 2032 kev, respectively. Final analysis of the continuous β spectrum is in process.

† Supported by the U. S. Atomic Energy Commission and the Higgins Scientific Trust Fund.
[1] E. P. Tomlinson, Bull. Am. Phys. Soc. Ser. II, 1, 296 (1956).

J7. Lifetime of a 1^- Level in Sm^{152}.† L. GRODZINS, *Brookhaven National Laboratory*.—A 960-kev state fed by K capture from Eu^{152m} [1] has recently been identified[2] as 1^- from internal conversion measurements of the 960- and 840-kev gamma transitions to the $0+$ ground state and $2+$ first exicted states of Sm^{152}. The ratio of reduced transition probabilities of the 960- and 840-kev transitions is 1:2[1] suggesting strongly that the 960-kev level is a member of the $K=0$ rotational band.[2]

We have attempted to measure its mean life by resonant scattering utilizing the width of the level to compensate for nuclear recoil [Γ single proton$^{(960\ kev)} \sim 2.5$ ev]. The 960-kev gamma rays from sources of Eu^{152m} were scattered by Sm_2O_3 placed in a ring around a 2×2 NaI crystal shielded from the direct radiation by 11 in. of Pb. The pulse-height distribution was examined with a 100-channel analyzer. Alternate scatterers of 10 g of Nd_2O_3 and Sm_2O_3 were used. No unambiguous effect attributable to resonant scattering was observed. The experiment indicates that the mean life $\tau \geq 3.5 \times 10^{-14}$ sec. This limit is $\sim 130\ \tau$ (single proton).

† Work performed under auspices of U. S. Atomic Energy Commission.
[1] L. Grodzins and H. Kendall, Bull. Am. Phys. Soc. Ser. II, 1, 163 (1956).
[2] O. Nathan and M. A. Waggoner (private communication).

J8. *K*-Shell Internal Conversion Coefficients of *M*1 γ Rays in Pu^{239}. G. T. EWAN, J. W. KNOWLES, AND D. R. MACKENZIE, *Chalk River Laboratories.*—The conversion coefficients of the γ rays of 209.7, 228.2, and 277.9 kev observed in the decay of Np^{239} have been measured using a curved crystal γ-ray spectrometer of two meters radius of curvature and a lens type β-ray spectrometer operated at 0.35% resolution. From a study of the K/L and $L_1:L_{11}:L_{111}$ conversion ratios, a limit has been placed on the possible admixture of $E2$ in these radiations. The values obtained for the conversion coefficients are listed below and compared with the theoretical values of Sliv[1] who allowed for finite nuclear size and with Rose *et al.*[2] who assumed a point charge for the nucleus. It is seen that for $Z=94$ the values calculated by Rose *et al.* are considerably higher than the experimental results.

γ ray (kev)	α_K Exptl.	$\alpha_K(M1)$ Theoret. Rose	Sliv	Limit on $E2$ admixture (%)
209.7	1.76±0.30	4.80	2.60	<20
228.2	1.60±0.16	3.84	2.05	<15
277.9	1.16±0.12	2.25	1.18	<10

[1] L. A. Sliv, Zhur. Eksptl. i Teort. Fiz. **21**, 77 (1951) and privately circulated tables.
[2] Rose, Goertzel, Spinrad, Harr, and Strong, Phys. Rev. **83**, 79 (1951).

J9. Attenuation of Am^{241} α-γ Angular Correlations in Liquid Film Sources.* V. E. KROHN, T. B. NOVEY, AND S. RABOY, *Argonne National Laboratory.*—Measurements of the α−γ correlation of Am^{241} have been carried out for liquid film sources. Attenuation of the angular correlation pattern with time was measured for hydrochloric acid, sulfuric acid, perchloric acid, and acetic acid media. For all but the acetic acid the exponential attenuation, as given by the theory of Abragam and Pound, was observed and the results obtained are $\lambda_2 = 13.5 \pm 2$ per μ sec for the hydrochloric and perchloric acid and $\lambda_2 = 21 \pm 2$ per μ sec for the sulfuric acid. These attenuation constants are independent of the concentration. The extrapolated value of A_2 for all α decays through the 59.6-kev state is $-0.31 \pm .02$. This number, corrected for the 14% α branch to the 103-kev level, will be compared to a prediction based on the rotational model.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

J10. Nuclear Spectroscopy of Neutron Deficient Isotopes in the Rare Earth Region. J. W. MIHELICH,* B. HARMATZ, T. H. HANDLEY, AND J. J. PINAJIAN, *Oak Ridge National Laboratory.*—Isotopes of elements Tb through Hf were produced by irradiations with 22 Mev protons in the Oak Ridge National Laboratories 86-in. cyclotron. Ion exchange separations were performed and sources for a 180° permanent magnet photographic-recording spectrograph were prepared by electrodeposition. Decay rates of the internal conversion lines were measured and these data, along with activation data and use of enriched isotopes, allowed us to make mass assignments for most of the sixteen activities observed. Two isomeric transitions of 5-hr half-life (Tb^{156m}, 88 kev; Ho^{160m}, 60 kev) have been established and are of electric character. Graphs of the energies of first and second excited states of even-even nuclei as functions of both proton and neutron number will be shown.

* Summer participant from the University of Notre Dame.

J11. Empirical Corrections to *M*1 Internal Conversion Coefficients. T. J. WARD AND J. W. MIHELICH, *University of Notre Dame.*—The theoretical prediction by Sliv[1] that the nuclear finite size should appreciably reduce the theoretical[2] $M1$ K- and L-shell internal conversion coefficients for high Z has been substantiated by recent experiments.[3] An analytical method, therefore, has been used to determine, under certain assumptions, the corrections as well as the mixing ratio in the case of $M1+E2$. The assumptions made were that (1) the electric quadrupole internal conversion coefficients need no correction, (2) there is a negligible correction to $\beta_1^{L_{III}}$, and (3) the total internal conversion coefficient, either electric or magnetic, is the algebraic sum of the subshell coefficients. A set of four independent equations can then be solved simultaneously which yield the correction factors and the mixing ratio. The experimental data needed to yield the results are the K- and total K-shell internal conversion coefficients and the L ratio. The set of equations thus developed adjusts the corrections to the K, L_1, and L_{11} conversion coefficients, denoted by "f," "g," and "h" (multiplicative factors) so that the absolute internal conversion coefficients and the L ratio are internally consistent. Several cases have been investigated so far, and the results are in general agreement with those previously repoted.[3]

[1] L. A. Sliv, Zhur, Eksptl. i Teort. Fiz. **21**, 77 (1951); L. A. Sliv and M. A. Listengarten, Zhur. Eksptl. i Teort. Fiz. **22**, 29 (1952).
[2] M. E. Rose, *Beta and Gamma Ray Spectroscopy*, edited by Kai Siegbahn (North Holland Publishing Company Amsterdam 1955), Appendix IV, p. 905.
[3] A. H. Wapstra and G. J. Nijgh, Nuclear Phys. **1**, 245 (1956); F. K. McGowan and P. H. Stelson, Phys. Rev. **103**, 1133 (1956).

J12. Effect of the Finite Nuclear Size on Internal Conversion.* E. L. CHURCH, *Brookhaven National Laboratory,* AND J. WENESER, *University of Illinois.*—The conversion calculations of Rose *et al.*[1] assume a point nucleus. Sliv *et al.*[2] show that the distortion of the electron wave functions by the finite charge distribution leads to major corrections to Rose's results, especially for $M1$ conversion. We now point out that *in addition:* (1) the penetration of the converting electron within the nucleus leads to *new nuclear matrix elements* for electron ejection, which are distinctly different from that for gamma-ray emission of the same multipole order and which obey different model-dependent selection rules. Sliv's model-dependent assumption of nuclear surface currents implicitly equates all matrix elements. (2) The presence of such new matrix elements can lead to discrepancies between experiment and Sliv's calculations. Conversion ratios and directional correlation experiments involving conversion electrons are also affected. (3) Since these effects depend on new nuclear matrix elements, their measurement gives new information on nuclear structure. Such effects exist for all electric and magnetic transitions. $M1$ conversion is analyzed in detail. When the gamma-ray matrix element is attenuated, e.g., for l-forbidden $M1$ transitions or the inhibited $M1$ components in odd-A rotational transitions, large effects (>50%) may occur.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] Rose, Goertzel, Spinrad, Harr, and Strong, Phys. Rev. **76**, 1883 (1949).
[2] L. A. Sliv and M. Listengarten, Zhur. Eksptl. i Teort. Fiz. **22**, 29 (1952).

FRIDAY AFTERNOON AT 2:30

Mandel Hall

(W. A. YAGER presiding)

Semiconductors, II

K1. Room-Temperature Polonium Alpha Irradiation of Germanium Single Crystals. M. W. BECKER AND K. LARK-HOROVITZ,* *Purdue University.*—Single crystal layers of germanium, small as compared to the range and thick as compared to the range of polonium alpha particles, have been irradiated at room temperature. The thickness of the samples has been determined optically, electrically, and by weight. The sources of polonium and their fluxes have been determined experimentally as well as estimated from geometry. The number of atoms displaced from regular lattice sites by collision have been calculated from Rutherford scattering and an estimate of secondaries produced by the primary displaced atoms. This has been compared with the removal rate of electrons or the rate of change of holes as a function of the Fermi level. 230 electrons per incoming alpha particle are removed in nearly degenerate n-type samples, whereas only 8 holes per incoming alpha particle are obtained on the p-type side. Removal rates calculated from conductivity are larger than the ones calculated from Hall effect measurements. Healing at room temperature on the n-type side is extremely slow, if existing at all; on the p-type side healing periods of the order of minutes and hours are observed.

* Supported by a Signal Corps contract.

K2. Effect of Dislocations on Lifetime in Germanium. G. K. WERTHEIM AND G. L. PEARSON, *Bell Telephone Laboratories.*—The decay of bombardment conductivity in plastically deformed 2.4 ohm cm, p-type germanium has been measured as a function of temperature and edge dislocation density. The samples were oriented to produce dislocations perpendicular to the plane of bending and were deformed at a temperature of about 700°C. Controls subjected to the heating cycle alone showed negligible deterioration in lifetime. To insure a reasonably uniform distribution of dislocations, samples were cut 0.060×0.130 in. in cross section and reduced to 0.030×0.100 in. by etching after bending. The decay of conductivity following electron bombardment excitation consists of two exponential functions probably corresponding to the trapping of electrons on dislocations and the subsequent recombination with holes. Results of measurements ranging from 150°K to 375°K in specimens having dislocation densities between 10^6 and $5\times10^7/\text{cm}^2$ will be discussed. A linear relationship between dislocation density and reciprocal lifetime is obtained. The room-temperature results of Okada[1] for naturally occurring dislocations ($\sim10^4/\text{cm}^2$) are in agreement with these results.

[1] J. Okada, J. Phys. Soc. Japan **10**, 1110 (1955).

K3. dc Magnetoconductivity and Energy Band Structure in Semiconductors.* R. M. BROUDY AND J. D. VENABLES, *National Carbon Research Laboratories.*—A technique of measurement will be described by which the dc magnetoconductivity tensor L can be computed from transverse and longitudinal magnetoresistivity tensor measurements as a function of $\mathbf{H}(\phi)$, the magnetic field in a plane of symmetry at the angle ϕ with respect to a symmetry axis. In this method, measurements are taken for various positions of H in x, y, and z planes of the usual rectangular sample. The angular dependence of the components of L is determined by the anisotropy of the band structure; the variation of L with $|\mathbf{H}|$ is determined by relaxation time, τ. For cubic materials, the experiments become simpler, requiring only a single sample cut with all 100-type planes. $L(H,\phi)$ has been theoretically determined on the basis of the theories of Bronstein[1] and Blochinzev and Nordheim[2]; the application of the theory to the cubic case predicts differing results of L *vs* ϕ for the different spheroidal structures. Experimental data on n-type germanium and silicon confirm other experimenters' results of 111- and 100-type spheroids, respectively.

* Submitted for the meeting of June 21–23 at New Haven. The abstract unfortunately was mislaid at the office of the Society.

[1] M. Bronstein, Physik. Z. Sowjetunion **V2**, 28 (1932).

[2] D. Blochinzev and L. Nordheim, Z. Physik **84**, 168 (1933).

K4. Electronic Band Structure of Selenium and Tellurium. JOHN R. REITZ, *National Carbon Research Laboratories.*—The band structure of selenium and tellurium has been calculated according to the tight-binding scheme in which only nearest neighbor interactions are presumed to be important. As a first approximation, von Hippel's hypothetical crystal with 90° bond angles between bonds in the chain was used, and the ninth degree secular equation for the p bands factored into three identical cubic equations. Next, the crystal was pulled out along the c axis to the observed bond angle, and further splitting of the p bands was calculated as a perturbation. The fifteen d bands were also computed, but mixing of p and d levels was only estimated. In addition, matrix elements for optical transitions between bands were worked out. The long wavelength absorption limit occurs at $k_s=\pi/c$, but it is not clear whether the lowest conduction level is p or d. Both $p\rightarrow d$ and $p\rightarrow p$ transitions show a difference in absorption edge for light polarized parallel or perpendicular to the c axis of the crystal; hence, either case is in accord with the experiments of Loferski[1] on tellurium.

[1] J. J. Loferski, Phys. Rev. **93**, 707 (1954).

K5. Hall and Drift Mobilities in the Ionized Impurity Scattering Regime.* F. J. BLATT, *University of Illinois and Michigan State University.*—Results obtained previously[1] have been used to calculate μ_H and μ_d when scattering by ionized impurities is dominant. It is found that the mobilities *do not* follow a $T^{\frac{3}{2}}$ law but increase less rapidly with temperature, in agreement with observation.[2] This conclusion is valid even in that range in which the Born approximation and the partial wave method give identical scattering cross sections. If one plots μ_H and μ_d as obtained from the Brooks-Herring formula for the relaxation time, the temperature variation of the mobilities is, in fact, less rapid than $T^{\frac{3}{2}}$; that is, the "logarithmic term" in the Brooks-Herring formula must not be neglected. The mobility ratio, μ_H/μ_d, is not $315\pi/512$ in the impurity scattering range but is somewhat less than this value and, moreover, is temperature dependent. The reason for this reduction from the previously quoted value and for the temperature dependence will be discussed. Curves of μ_H, μ_d and μ_H/μ_d for a typical case will be presented.

* Supported in part by the Office of Naval Research.

[1] F. J. Blatt, Bull. Amer. Phys. Soc. Ser. II, **1**, 48 (1956); also internatl. J. Phys. Chem. Solids (to be published).

[2] P. P. Debye and E. M. Conwell, Phys. Rev. **93**, 693 (1954).

K6. Infrared Optical Constants and Effective Mass of Carriers in Semiconductors.* W. SPITZER AND H. Y. FAN, *Purdue University.*—Optical constants, refractive index, and extinction coefficient have been determined for a number of

semiconductors by measuring reflection and transmission in the region 1 to 30 μ. The effect of free carriers on the optical constants was determined from these measurements. With sufficiently high carrier concentrations, the reflectivity shows a pronounced minimum, rising to high values at long wavelengths. The contribution of free carriers to the electric susceptibility was obtained. In all cases, the susceptibility is proportional to the wavelength squared as expected for free carriers when the radiation frequency is high compared to the collision frequency. Knowing the carrier concentration from electrical measurements, the conductivity effective mass can be obtained from the susceptibility. The effective mass results are 0.15 for n-type germanium, 0.27 for n-type silicon, 0.37 for p-type silicon, 0.029 for n-type InSb, 0.20 for p-type InSb, and 0.033 for n-type InAs. The values for germanium and silicon are in reasonable agreement with values expected from cyclotron resonance. The n-type InSb result agrees with the value obtained from the shift of the intrinsic absorption edge with electron concentration but not with the cyclotron resonance value. The electron carrier concentration of the sample used here is relatively high, $n_e = 6.3 \times 10^{17}$ cm^{-3}.

* Work supported by an Office of Naval Research Contract.

K7. Combination of Scattering by Optical Modes and by Acoustical Modes in a Degenerate Semiconductor.* V. A. JOHNSON, *Purdue University.*—If conduction electrons are subject to two simultaneous scattering processes characterized by different energy dependences of the mean free paths, a combined mean free path must be used in the calculation of electrical properties. Previous calculations have been made only for classical semiconductors. The present computation is made for impurity semiconductors with positive values of the Fermi level under the assumption that both lattice scattering (l independent of carrier energy) and polar scattering (l approximately proportional to carrier energy) are present. In the classical semiconductor the combined resistivity is up to 11% greater than the sum of the two components, but, as the degree of degeneracy increases, this difference decreases, and the separate resistivity components are simply additive in a highly degenerate sample. The mean-free-path term in the thermoelectric power increases with increasing degeneracy and also increases about linearly as the scattering varies in nature from pure lattice scattering to pure polar scattering. For all positions of the Fermi level, the dimensionless factor in the Hall coefficient shows a U-shaped curve when plotted against the fraction of polar scattering present. With increasing degeneracy, there is little change in the position of the minimum, but the end values become lower.

* Work assisted by a U. S. Signal Corps contract.

K8. Electron Bombardment of Indium Antimonide.* L. W. AUKERMAN AND K. LARK-HOROVITZ, *Purdue University.*—Bombardment of single crystal specimens of InSb with 4.5-Mev electrons decreases the carrier mobility and changes the carrier concentration, depending on the initial Fermi level and the temperature of the bombardment. At approximately 230°K or lower temperatures n type is converted to p type with sufficient bombardment. Annealing experiments indicate that four types of defects are produced which anneal at different temperature regions: at 80–85°, 120–150°, 250–330°, and the fourth does not anneal below 373°K. The defects which anneal below 250°K are complicated and cannot be explained in terms of simple vacancy-interstitial recombination. The defects which anneal at 250–330°K are donors and acceptors and are assumed to be vacancies and interstitials. Analyses of bombardments carried out at 200–240°K indicate that these acceptor and donor levels lie at approximately 0.035 and 0.082 ev above the valence band, respectively. From the magnitude of the changes in mobility it is inferred that there are doubly ionized levels. The defects which remain at 373°K are mostly donors with an activation energy greater than 0.03 ev below the conduction band.

* Work supported by a U. S. Atomic Energy Commission contract.

K9. Electron Scattering in InSb. H. EHRENREICH, *General Electric Research Laboratory.*—The electron mobility and thermoelectric power of InSb have been calculated in the temperature range 200 to 500°K assuming scattering by acoustical and optical phonons and holes. The nonparabolic conduction band theory of Kane[1] and the cyclotron resonance mass 0.013 m were used. A systematic treatment of acoustic mode scattering, neglecting small piezoelectric effects,[2] shows deformation potential scattering dominant, but too small to explain the observed mobility. Only the polar interaction couples electrons to optical modes in InSb. Transport theory developed to treat this interaction[3] has been extended to apply to nonparabolic bands. The calculated mobility agrees closely with experiment[4] over the specified temperature range for a reasonable choice of the effective ionic charge e^*. Excellent agreement between the theoretical thermoelectric power, which is independent of e^*, and experiment[5] is also obtained for the 0.013 effective mass. Electron-hole scattering is significant at temperatures above 500°K.

[1] E. O. Kane, Bull. Am. Phys. Soc. Ser. II, 1, 285 (1956).
[2] W. A. Harrison, Phys. Rev. 100, 903 (1955).
[3] D. J. Howarth and E. H. Sondheimer, Proc. Roy. Soc. (London) A219, 53 (1953).
[4] Hrostowski, Morin, Geballe, and Wheatley, Phys. Rev. 100, 1672 (1955).
[5] H. Weiss, Z. Naturforsch. 11a, 131 (1956).

K10. Temperature Dependence of Electron Localization in InSb. R. J. SLADEK, *Westinghouse Research Laboratories.*—Application of a strong magnetic field to n-InSb at 4.2°K reduces the number of mobile electrons,[1] presumably due to the shrinking of the electronic wave functions with an accompanying increase in the energy of binding between a donor ion and an electron.[2] To obtain quantitative information on this effect we have measured the Hall coefficient and resistivity at several temperatures in the liquid helium range, in fields up to 30 000 gauss, on n-InSb samples kindly provided by Dr. A. Beer of the Battelle Memorial Institute. Using a crude model consisting of a band responsible for conduction and localized bound states, we have obtained values for the donor-electron binding energy between 10 000 and 30 000 gauss. Measurements of the Hall coefficient as a function of electric field indicate that electrons localized by the magnetic field can be re-excited into conducting states.

[1] R. W. Keyes and R. J. Sladek, Phys. Rev. 100, 1262(A) (1955); H. P. R. Frederikse and W. R. Hosler, Bull. Am. Phys. Soc. Ser. II, 1, 298 (1956).
[2] Yafet, Keyes, and Adams, Internatl. J. Phys. Chem. Solids (to be published).

K11. Measurement of Resistivity and Mobility of Silicon and Indium Antimonide Ingots.* J. J. DUGA, A. C. BEER, AND R. K. WILLARDSON, *Battelle Memorial Institute.*—Various methods used to obtain a profile of the resistivity, mobility, and Hall coefficients of silicon and indium antimonide ingots at 80 and 300°K are described and the results compared. The standard two- or four-probe arrangements have been modified to incorporate easily interchangeable probes of different metals. Contact resistance and rectification were reduced by electroforming probes containing donor or acceptor materials for n- or p-type silicon, respectively.[1] Four probes in a diamond shape gave a direct measurement of the carrier mobility from the ratio of the transverse and longitudinal potential gradients. Low resistance contacts are obtained by using rhodium-plated dots. Approximate determinations of resistivity were also done without the use of contacts by noting the change of the Q of a small test coil in close proximity to the ingot.[2] The

relative precision of these methods was determined by cutting specimens from the ingots and accurately measuring their properties.

* Supported in part by the A. F. Cambridge Research Center.
[1] R. H. Creamer, Brit. J. Appl. Phys. **7**, 149 (1956).
[2] H. K. Henisch and J. Zucker, Rev. Sci. Instr. **27**, 409 (1956).

K12. Donor Defect Control in Polycrystalline PbTe. R. W. FRITTS AND S. KARRER, *Milwaukee Gas Specialty Company.*—Annealed polycrystalline ingots of PbTe containing a slight lead excess exhibit *N*-type carrier concentrations limited to less than 10^{18}/cc. Additions of Bi, Ta, Mn, Zr, Ti, Al, Ga, Cl, Br, I, or *U* can be incorporated into the melt to increase the carrier concentration beyond 10^{19} electrons/cc. Resistivity-temperature plots and Seebeck emf data are given for a range of bismuth additions to slightly lead-rich PbTe. All of these third element additions form compounds with lead or tellurium that can be represented by the formula A_xB_y, in which *A* is the more metallic component. For each compound that induces donor levels the ratio x/y is found to be less than unity. These donor forming species have a sufficiently high heat of formation to be expected to exist in equilibrium with liquid PbTe and the slight lead excess. It is proposed[1] that upon freezing an appropriate number of PbTe molecules is substitutionally replaced by a molecule of the additive species plus an uncharged Schottky-type lead vacancy. The donor defect is established when an excess lead atom migrates into this vacancy and releases an electron to ionization.

[1] C. Wagner, J. Chem. Phys. **18**, 62 (1950).

FRIDAY AFTERNOON AT 2:30

Oriental 272

(C. S. BARRETT presiding)

Metals

L1. Mechanical Strength of Thin Films of Silver and Gold.* W. K. FORD, JR., A. L. STAMPER, AND J. W. BEAMS, *University of Virginia.*—The tensile strengths of thin evaporated films of silver and gold have been determined as a function of film thickness by the "bulge" method. The metal film is mounted over the open end of a cylindrical tube and its bulge measured at various air pressures inside the tube until the film bursts. From these data the tensile strength can be determined.[1] The tensile strengths are sensible constant (1.1×10^9 dynes/cm^2 for silver and 0.9×10^9 dynes/cm^2 for gold) at thicknesses greater than 2.5×10^{-5} cm for silver and 2×10^{-5} cm for gold. At thicknesses below 2×10^{-5} cm for silver and 1.5×10^{-5} cm for gold, there is a marked increase in tensile strength. These results are in good qualitative agreement with those found with electrodeposited silver films by the centrifugal method.[2] The quantitative differences are believed to be due to variations in the stress patterns, differences in methods of deposition, and possible slight adhesion in the case of the centrifugal experiments.

* Supported by the Office of Ordnance Research, U. S. Army.
[1] A. G. Gleyzal, Trans. Am. Soc. Mining Met. Engrs. **70**, 288 (1948).
[2] Beams, Breazeale, and Bart, Phys. Rev. **100**, 1675 (1955).

L2. Torsional Strain and the Screw Dislocation in Whisker Crystals. R. G. TREUTING, *Bell Telephone Laboratories* (introduced by R. D. Heidenreich).—It has been shown theoretically by J. D. Eshelby that the presence of a screw dislocation in a fine whisker crystal should result in a torsional strain of appreciable magnitude. Theoretical opinion has been divided as to whether a spontaneously grown whisker should contain a screw dislocation. The Weissenberg x-ray pattern of a crystal oscillated about a twist axis reveals such strain by elongation of the reflection spots to extended streaks. The effect has been found in the patterns of three spontaneously grown tin whiskers. From the strain in each, determined from the pattern, the whisker diameter is calculated and compared with the optically measured value. Agreement is within a factor of three; the torsional strain is of the order required by the presence of a screw dislocation in the whisker. The method will also show evidence of plastic strain, in particular the presence of dislocation twist boundaries, found in one of the specimens and considered the result of handling and mounting.

L3. Torsion Induced Recrystallization of Highly Refractory Filaments.* F. GIFFORD AND E. COOMES, *University of Notre Dame.*—Single crystals up to 15 cm length were grown repeatedly in 2 to 5-mil Mo and W filaments, after twisting these filaments from 2 to 10 turns per inch. The moving gradient method with 2000°K for Mo and 2800°K for W was used. Observations with an electron projection microscope showed a uniform screw-like pattern of high electron emission superimposed upon the projection pattern of the single crystal. This is apparently due to impurities in an otherwise perfect crystal.

* Work supported in part by the Office of Naval Research and U. S. Atomic Energy Commission.

L4. The Influence of Torsion on Crystal Growth in Molybdenum Filaments by the Robinson Method.* J. SHILTS AND E. COOMES, *University of Notre Dame.*—Recrystallization of previously twisted Mo filaments has been carried out by the Robinson method.[1] Variation of the parameters twist strain and temperature indicate that (1) there is an optimum twist for a given temperature, and (2) there is a limit to the temperature range for a given twist. For the particular wires used, the longest crystals were obtained for a twist of about 4 turns per inch and a temperature of about 1650°K.

* Work supported in part by the Office of Naval Research and U. S. Atomic Energy Commission.
[1] C. S. Robinson, J. Appl. Phys. **13**, 647 (1942).

L5. Calculation of the Elastic Shear Constants of Magnesium Alloys.* C. S. SMITH AND J. R. REITZ, *Case Institute of Technology.*—Leigh's[1] calculation of the shear constants of aluminum are extended to crystals of lower symmetry, i.e., to magnesium and dilute magnesium alloys. The requirement that pure magnesium be in equilibrium with respect to shears that change its c/a ratio is consistent only with electron overlap having already occurred across the Brillouin zone faces perpendicular to the *c* axis, a result at variance with the usual assumptions for this metal. Assuming *c* overlap and one other overlap in the pure metal, it is found that the total number of overlap electrons is 1.70×10^{21} cm^{-3}, i.e., 2% of the valence electrons. The overlap appearing at 2.01 electrons/atom is assumed to be in the equatorial plane of the Brillouin zone; it produces an abrupt change in one of the shear constants as

the electron/atom ratio is increased, a behavior of the type predicted by Leigh for aluminum alloys. The abrupt change in constant is characteristic of $T=0°K$; however, at room temperature the predicted effect is more gradual and in accord with experiment.

* Work supported by the Office of Naval Research and the National Carbon Company.
[1] R. S. Leigh, Phil. Mag. **42**, 139 (1951).

L6. Electrical Resistivity of Nickel Palladium Alloys. A. I. SCHINDLER, *Naval Research Laboratory*, AND A. W. OVERHAUSER, *Cornell University*.—The concentration dependence of the residual resistivity of Ni-Pd alloys might be expected to obey a simple Nordheim law since the number of holes in the *d* band and the number of electrons in the conduction band are approximately independent of composition. Measurements have indicated, however, that the maximum resistivity occurs at 70 atomic % Pd instead of 50%. This behavior can be explained by the spin dependence of electron scattering processes associated with the fact that the alloys with greater than 3% Ni are ferromagnetic. For Ni, electrons in the *s* band with spin antiparallel to the saturation magnetization cannot be scattered into the *d* band. Consequently, these electrons have high conductivity and act to short circuit the high resistance associated with the electrons of opposite spin, which are scattered predominantly into the *d* band. Since the saturation magnetization decreases with increasing Pd content, this short-circuit effect decreases, and the residual resistivity maximum is shifted toward the Pd-rich end. Quantitative fit of the data is possible if it is assumed that the density of states at the Fermi energy in the *d* band is approximately proportional to the number of holes, rather than to the cube root of this number. Data on the resistivity and paramagnetic susceptibility of Ag-Pd alloys support this hypothesis. The relative strength of $s-d$ scattering to $s-s$ scattering must be assumed to be about 6:1.

L7. Conductimetric Investigation of G.P. Zone Formation in Al-Cu Alloy. D. TURNBULL AND H. N. TREAFTIS, *General Electric Research Laboratory*.—When Al-Cu (2 atom % Cu balance Al) alloy is quenched from the solution temperature, T_s(*ca* 823°K), to temperatures $<T_\omega$433°K, the copper segregates into Guinier-Preston (G.P.) zones.[1] Near room temperature the conductance L decreases with time t by as much as 4 to 5%, concurrent with zone formation. We have measured this conductance decrease ΔL, for the temperature range 223 to 303°K, as a function of time and temperature history. The isothermal dependence of ΔL on t is described satisfactorily by $d(\Delta L)/L_0dt=m_i=k/(t+b)$ where L_0 is the conductance at $t=0$ and $T=273°K$. If the quench ($T_s\rightarrow T<303°K$) is interrupted by holding for a period t_i(0 to 60 sec) at an intermediate temperature $T_i\omega 473°K>T_s$ (i.e., $T_s\rightarrow T_i\rightarrow T<303°K$), $k/b=m_0$ varies as $1/(t_i+c)$. Thus, m_0 at 273°K is 10.5 times greater for $t_i=0$ (direct quench) than for $t_i=10$ sec ($T_i=473°K$). L_0 increases 0.4% at most because of the intermediate holding. For $t_i=0$, m_0 increases exponentially with $(-1/T)$, the activation energy being 10 ± 1 kcal/g atom; at $T=273°K$, $k=4.9\times10^{-3}$ and $b=6.2$ sec. At constant T and $\Delta L/L_0$, m_i (for $t_i=0$) is independent of temperature cycling in the range below 303°K.

[1] For review see H. K. Hardy and T. J. Heal, *Progress in Metal Physics* (Pergamon Press, London, 1954), Vol. 5, pp. 143–279.

L8. Calorimetric Investigation of G.P. Zone Formation in Al-Cu Alloy. W. DESORBO AND D. TURNBULL, *General Electric Research Laboratory*.—Measurements on the time dependence of the isothermal evolution of energy, E, have been made on Al-Cu (atom fraction of Cu=0.02) alloy after quenching from the solution temperature, T_s(~813°K) →300°K. The isothermal time dependence of E is found to be similar to the conductance (ΔL) time dependence reported by Turnbull and Treaftis.[1] That is, $\dot{x}_i=dE/dt=k'/(t+b')$ where $k'=11.8\pm0.3$ cal/g atom of alloy and $b'=7.5\pm0.2$ min. For example, $\dot{x}_{20\text{ min}}=0.43$ (water quenched). In contrast to the conductance studies, the quenching rates are slower and the time of first measurement is about 10 min after the quench. When the quenching procedure is changed to T_s, 823°K →473°K (10 sec)→300°K, $\dot{x}_i$ decreases ($\dot{x}_{20\text{ min}}=0.14$). By quenching from T_s directly into water (300°K), $E_{60\text{ min}}=24\pm3$ cal/g atom; while quenching from T_s into silicone oil (300°K), $E_{60\text{ min}}=10\pm2$ cal/g atom and $\dot{x}_{20\text{ min}}=0.20$. The latter results are in fair agreement with those of Borelius *et al.*[2]

[1] D. Turnbull and H. N. Treaftis, preceding abstract.
[2] Borelius, Anderson, and Gullberg, Ingen. Vetensk. Akad. Handl. Nr. 169 (1943).

L9. The *K*-Emission Spectrum of Metallic Lithium.† D. E. BEDO* AND D. H. TOMBOULIAN, *Cornell University*.—The emission spectrum of an evaporated lithium target has been investigated in the spectral region extending from 60 A to 600 A. The intensity distribution of the characteristic *K*-emission band has been determined photometrically. Some features of the distribution $I(E)/\nu^3$ are as follows. The band has a maximum at 54.02 ev (229.50 A); the distribution has dropped to one-half of its maximum value on the high-energy side at 54.58 ev; the decay in intensity from the peak to the high-energy limit of the band occurs in an energy interval of 1.18 ev; and the full extent of the recorded radiation is 4.45 ev. The observed distribution varies as the $\frac{1}{3}$ power of the energy over a region 1.0 ev in extent on the low-energy side of the maximum. The band does not show a sharp high-energy cutoff and the shape agrees fairly well with that obtained by Skinner.[1] A second band, similar in shape and having a maximum at 82.83 ev, has been observed and is presently identified as a *K* satellite.

† Supported in part by the Office of Ordnance Research, U. S. Army.
* Now Corning Glass Fellow.
[1] H. W. B. Skinner, Phil. Trans. Roy. Soc. (London) **A239**, 95 (1940).

L10. Absorption Spectrum of Cobalt in the Vicinity of the $M_{2,3}$ Edge.* J. H. DENNY† AND D. H. TOMBOULIAN, *Cornell University*.—The absorption spectrum of thin evaporated cobalt foils was investigated in the spectral region extending from 60 A to 200 A. The vaporized metal was condensed on a substrate consisting of a *P*yrex slide coated with Victawet and Zapon layers. Following deposition, the foil was floated off the glass by dissolving the wetting agent and then was mounted on an aluminum holder. The estimated thicknesses of the various absorbers, as determined by weighing, ranged from 300 A to 700 A. A large dip in the absorption curve occurring at about 207 A is identified as the $M_{2,3}$ edge, corresponding to the onset of $3p\rightarrow$conduction band absorption. The wavelength position of the discontinuity is in accord with the previously[1] observed edge in the $M_{2,3}$ emission spectrum. The absorption coefficient, μ, on the low-energy side of the edge is approximately 8×10^5 cm^{-1}, while the change in μ at the edge is 3×10^5 cm^{-1}.

* Supported by the Office of Ordnance Research, U. S. Army.
† Now at General Electric Electronics Laboratory, Syracuse, New York.
[1] Skinner, Bullen, and Johnston, Phil. Mag. **45**, 1070 (1954).

L11. Electron Irradiation of Copper below 10°K. I. M. D. FISKE, R. M. WALKER, J. W. CORBETT, AND J. M. DENNEY, *General Electric Research Laboratory*.— High-purity copper foil maintained at temperatures below 10°K has been bombarded by 1.35-Mev electrons, and the change in electrical resistivity at 4.2°K has been measured during the course of bombardment and subsequent annealing. The 0.0032-cm foil was rolled from zone-refined ASR copper, annealed, and photoengraved to

reproduce a pair of similar specimens having a bulk resistivity of $1.5\times10^{-9}\Omega$ cm at 4.2°K. Only one specimen was irradiated, the other being used as control. They were attached at either end to a mounting within a cylindrical Be-Cu pillbox provided with 0.02-cm Be windows normal to the electron beam. The pillbox was so mounted that the specimens were completely immersed in a flow of helium during irradiation. A heater wire was cemented to the exterior of the pillbox; control of the heater current and of the helium flow rate controlled the temperature either during irradiation or during subsequent pulse annealing. Thermometry was provided by two carbon resistors, by a thermocouple, and by the temperature dependent resistance of the specimen. High-energy electrons were supplied by an accelerator of the resonant transformer type gated to the central 34° of the voltage sine wave. Details will be presented concerning calibration of the electron beam energy and current density.

L12. Electron Irradiation of Copper below 10°K. II. R. M. WALKER, J. W. CORBETT, J. M. DENNEY, AND M. D. FISKE, *General Electic Research Laboratory.*—The resistivity change has been measured in a thin, high-purity copper foil irradiated at ambient temperatures <10°K with 1.35-Mev electrons. The added resistivity was found to be linear with total electron dose up to the maximum dose employed o $\sim10^{17}$ electrons/cm². The best value or the resistivity change/electron/cm², ρ_e, is $(8.25\pm1.2)\times10^{-27}$ ohm cm/electron/cm². Runs taken with different beam currents and at slightly higher temperatures gave essentially the same result, indicating the absence of thermal annealing during irradiation. The simple model of the damage process, assuming a threshold of 25 ev, predicts a cross section of 44 barns[1] for the production of interstitial vacancy pairs by these electrons. If this model is valid, the measured value of ρ_e would indicate a value of $\sim1.9\ \mu$ ohm cm for the resistivity of 1 atomic % of Frenkel pairs. Isothermal and isochronal anneals which have been performed on the sample will be discussed. No resistivity is observed to anneal out below 21°K while 90% has annealed out by 65°K. If one makes the maximizing assumption that only interstitials are annealing and no vacancy annihilation occurs, then the ratio of initial to final resistivities gives the value 10 for the maximum ratio of interstitial to vacancy resistivities. The annealing does not appear to be describable by a single first- or second-order rate equation.

[1] F. Seitz and J. S. Koehler, *Solid State Physics* (Academic Press, Inc., New York, 1956), Vol. II.

L13. Resistivity of Interstitials and Vacancies in Cu. J. M. DENNEY, *General Electric Research Laboratory.*—Recent results of electron irradiation of Cu below 10°K[1] can be employed to estimate the resistivity of interstitials and vacancies in Cu. A lower limit of 1.9 μ ohm cm/% for the resistivity of a Frenkel defect has been obtained.[1] An upper limit is obtained by taking 1.0 μ ohm cm/% for the vacancy resistivity[2] and the experimental result that 90% of the resistivity anneals below 80°K, yielding 10 μ ohm cm/% as an upper limit. An estimate of the resistivity can be made by assuming impurity and dislocation densities and calculating the fraction of vacancies likely to escape annihilation by the annealing interstitials, yielding 5 μ ohm cm/% Frenkel defects. A further estimate can be made by assuming a displacement probability, $p(E)$, and performing a modified Mott-Rutherford calculation. The best estimate obtained in this manner appears to be 7 μ ohm cm/% Frenkel defects. The resistivity of Frenkel defects in Cu, therefore, would appear to be greater than calculated by Blatt[2] and less than the value obtained by Overhauser and Gorman.[3]

[1] Corbett, Denney, Fiske, and Walker, Phys. Rev. (to be published).
[2] F. J. Blatt, Phys. Rev. **99**, 1708 (1955).
[3] A. W. Overhauser and R. L. Gorman, Phys. Rev. **102**, 676 (1956).

FRIDAY EVENING AT 7:00

Quadrangle Club

(E. P. WIGNER presiding)

Banquet of the American Physical Society

After-dinner speakers: E. U. CONDON, J. E. GOLDMAN

SATURDAY MORNING AT 9:30

Mandel Hall

(E. P. WIGNER presiding)

Invited Papers on New Particles and Cosmic Rays

M1. Interactions of *K*-Particles Stopping in Hydrogen. ROBERT TRIPP, *University of California, Berkeley.* (30 min.)

M2. Observations of Long-Lived Neutral *V* Particles. WILLIAM CHINOWSKY, *Brookhaven National Laboratory.* (30 min.)

M3. The Low *Z* Component of the Primary Cosmic Radiation. F. B. MCDONALD, *State University of Iowa.* (30 min.)

SATURDAY MORNING AT 9:00

Cobb 110

(S. N. GUPTA presiding)

Theoretical Physics

N1. Scattering of Charged Nuclear Particles by Ellipsoidal Nuclei.* J. S. BLAIR AND F. G. MAJOR, *University of Washington.*—Using the impulse approximation, justified when the nuclear collision time is short compared to the period for nuclear rotation, and neglecting effects due to the electric quadrupole interaction, Drozdov[1] has derived expressions for cross sections into the various nuclear rotational states in terms of the scattering amplitudes from stationary ellipsoidal nuclei suitably averaged over possible orientations. Drozdov's results have been extended and applied to the case of intermediate energy alpha scattering treated in the semiclassical strong absorption model.[2] This semiclassical model is particularly amenable to the foregoing calculation since the nuclear orientation and deformation are simply related to the only nuclear parameter in the model, the cut-off radius. Numerical results are presented for the energy dependence of alphas scattered at 60° by U and 42° by Ta for several values of the deformation parameter.

* This work supported in part by the U. S. Atomic Energy Commission.
[1] S. I. Drozdov, Soviet Phys. 1, 591 (1955).
[2] J. S. Blair, Phys. Rev. 95, 1218 (1954).

N2. Scattering of Neutrons by a Spheroidal Complex Potential.* E. TROUBETZKOY AND B. MARGOLIS, *Columbia University.*—The zero energy scattering of neutrons by a complex square-well potential of the form

$$V=-V_0(1+i\zeta) \qquad r<R(1+aP_2)$$
$$=0 \qquad r>R(1+aP_2)$$

$V_0=42$ Mev, $\zeta=.03$, is being investigated. The wave functions inside and outside the square-well boundary are expanded in terms of complete sets of solutions consisting of the appropriate spherical Bessel and Neumann functions times spherical harmonics. These wave functions are joined in value and slope on the surface $r=R(1+aP_2)$ at angular positions given by the roots of $P_{2l}=0$. Enough l values are included until convergence obtains. A machine program is underway and results have been obtained for eccentricities $\eta=\frac{3}{2}a=\pm.075$. The strength function Γ/D has a resonance at $A\sim173$ (using $R=1.26A^{\frac{1}{3}}+0.7$) for a spherical nucleus. This resonance has split into two smaller resonances using the foregoing eccentricities. Further results will be reported at the meeting.

* This work was partially supported by the U. S. Atomic Energy Commission.

N3. High-Energy Contributions in the Low Equations for *P*-Wave Pion-Nucleon Scattering.* GEORGE SALZMAN, *University of Rochester*, AND FREDA SALZMAN, *Rochester.*—The Low equations for pion-nucleon scattering[1] in the static nucleon theory are used to examine the high-energy contributions to the low-energy phase shifts. It is found, independent of the cutoff, that for $f^2=0.08$, if the theory is to give δ_{33} correctly and the other P-wave phase shifts small in the P-wave resonance region, then high-energy contributions cannot be neglected, particularly in the (1,1) equation. With $f^2=0.08$ there is further verification of the validity of the effective range approximation for the (3,3) state. A higher vaule of f^2 appears to be ruled out by the small experimental value of δ_{11}. The nature and magnitude of the high-energy contributions will be discussed. A numerical solution of the Chew-Low equations for the one meson approximation[1] has been obtained[2] which exhibits the features to be expected on the basis of the more general discussion indicated in the foregoing.

* Supported in part by the U. S. Atomic Energy Commission.
[1] G. F. Chew and F. E. Low, Phys. Rev. 101, 1570 (1956).
[2] G. Salzman, *Proceedings of the Sixth Annual Rochester Conference on High Energy Nuclear Physics* (Interscience Publishers, Inc., New York, 1956).

N4. Fierz Interference and the Beta Spectrum of He^6.† A. SCHWARZSCHILD, B. M. RUSTAD, AND C. S. WU, *Columbia University and Brookhaven National Laboratories.*—A careful investigation of the shape of the allowed beta spectrum of He^6 should set an upper limit on the ratios of the coupling constants, C_A/C_T and C_P/C_T in beta decay.[1–3] A detailed study of scattering effects in our thin lens spectrometer has been made. It enables one to interpret the spectrum shape from the end point at $W_0=3.50\pm.02$ Mev down to $1/14W_0=0.250$ Mev. If the very likely assumption that $[|C_P/C_T|]<10$ is made, then the comparison of the spectrum shape with that expected from the Fierz interference correction factor in the Gamow-Teller interaction, $[1+(2C_A/C_T\epsilon)]$, indicates that $-0.15<C_A/C_T<+.04$. An upper limit can be set on C_P/C_T if C_A/C_T is assumed to be zero. The relatively small effects of nuclear recoil energy and inner bremsstrahlung production on the shape of allowed spectra will be discussed.

† This work was partially supported by the U. S. Atomic Energy Commission.
[1] C. S. Wu, *Beta and Gamma Ray Spectroscopy*, edited by H. Siegbahn (Interscience Publishers, Inc., New York, 1955), p. 314.
[2] De Groot and Tolhoek, Physica **XVI**, 456 (1950).
[3] Alaga, Kofoed-Hansen, and Winther, Dan. Mat. Phys. Medd. 28, No. 3 (1953).

N5. (Abstract withdrawn.)

N6. An Interpretation of New $d\phi$ Experimental Data in Terms of the *j-j* Coupling Shell Model.* B. J. RAZ, *Argonne National Laboratory.*—An analysis of the $d\phi$ results in the calcium isotopes has been done by French and Raz.[1] This pro-

cedure is now used to interpret new data from the following experiments: $Cr^{52,53}(pd\theta)Cr^{53,54}$[2]; $A^{40}(dp\theta)A^{41}$ and $Ne^{20,22}(dp\theta)Ne^{21,23}$[3]; and perhaps on $Ne^{21}(dp\theta)Ne^{22}$. As with calcium this work has identified new single-particle and multiparticle levels in these isotopes. Of particular interest is the identification of the 0.97-Mev level in Cr^{53} as the previously unobserved $f_{5/2}$ single-particle level. Also, the relative cross sections are consistent with pure $j-j$ coupling for all these cases. Suggested experiments, which would yield valuable new information on locations and identification of levels and on departures from $j-j$ coupling, include $Ca^{43,46,48}(dp\theta)Ca^{44,47,49}$; $Ti^{46}(dp\theta)Ti^{47}$; $Cr^{50,54}(dp\theta)Cr^{51,55}$, $Fe^{54,58}(dp\theta)Fe^{55,59}$; $Ni^{58,60,62}(dp\theta)Ni^{60,61,63}$ and $Zi^{64,66,67,70}(dp\theta)Zi^{65,67,68,71}$.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] French and B. J. Raz, Phys. Rev. (to be published).
[2] A. J. Elwyn and F. P. Shull, Bull. Am. Phys. Soc. Ser. II, 1, 281 (1956) and private communication.
[3] Burrows *et al.* Proc. Phys. Soc. (London) **A69**, 310 (1956).

N7. Integral Equations for the Transition Matrices in the Static Meson Theory.* NOBUYUKI FUKUDA AND JULIUS KOVACS, *Indiana University.*—The Chew-Low-Wick integral equation for the scattering matrix in the static meson theory has been generalized so as to make it possible to treat the various pion processes in which arbitrary numbers of pions are involved. Such a generalization is also necessitated if one wants to take into account the contribution of two or more meson configurations in pion-nucleon scattering. The outgoing or incoming wave functions corresponding to the many-meson initial states are defined in the same manner as by the aforementioned authors in the one-meson problem and are shown to be identical with those introduced by Lippmann and Schwinger. An approximate expression for the two-meson production matrix is obtained and some correction terms due to this production are derived for Chew-Low one-meson equation.

* Supported by the National Science Foundation and the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

N8. *K*-Meson Nucleon Interactions. WALTER THIRRING, *Institute for Advanced Studies.*—It has been suggested to consider hyperons as elementary* or as compound† particles. It seems that the two pictures will lead to different predictions for the K-meson nucleon scattering. In the former picture K^+N scattering will go via the intermediate state $2K^+$+hyperon, whereas K^-N will have an intermediate hyperon. As in pion-nucleon scattering the former corresponds to an attractive and the latter to a repulsive force. This may be overshadowed, however, by a direct $\pi-K$ interaction on the absorptive processes in the K^-N system. In the Goldhaber model the hyperon is supposed to be a bound state between a K^-K_0 and a nucleon. Making the "ansatz" $U_1+\tau_K\tau_N U_2$ for the K-meson nucleon potential, we estimate U_1 and U_2 by the position of the singlet (Λ) and triplet (Σ) state. Calculating the $2K$-nucleon system we find the doublet level at the observed Ξ mass and the stable quartet 110 Mev above the Ξ. Furthermore, the potential leads to an attractive, almost isospin independent, K^--nucleon scattering.

* Nishijama model.
† Goldhaber model.

N9. On the Forces between Hyperons and Nucleons.* D. B. LICHTENBERG AND MARC ROSS, *Indiana University.*—The forces between Σ particles and nucelons can be evaluated using a model adopted previously in a calculation of the Λ-nucleon force.[1] This model assumes that the forces are due only to pions, assigns a spin of $\frac{1}{2}$ to the Λ and Σ, and gives them the same parity. The evaluation is carried out to fourth order in the coupling constant using an approximation which neglects the $\Lambda-\Sigma$ mass difference compared to the energy of a virtual pion. The same diagrams occur as for the nucleon-nucleon potential plus the Λ-nucleon potential except for differences in coupling constant and isotopic spin. In the state of isotopic spin $T=\frac{3}{2}$, the potentials have the same form, upon appropriate modification of the coupling constant, as in the $T=1$ two nucleon case (beyond the range of the repulsive core). If it is assumed that the coupling constant-core combination for the process $\Sigma\leftrightarrow\Sigma+\pi$ is the same as that obtained in reference 1 for $\Sigma\leftrightarrow\Lambda+\pi$, the magnitude of the potentials are specified. It is found that the Σ^+-proton potential is much too weak to form a bound state. The model also predicts the $\Sigma-\Lambda$ force.

* Supported by the National Science Foundation.
[1] D. B. Lichtenberg and Marc Ross, Phys. Rev. **103**, 1131 (1956).

N10. Spinor Fields and Gravity.* F. J. BELINFANTE AND W. L. KENNEDY, *Purdue University.*—Since our last report,[1] we have explicitly calculated Dirac's modified Poisson Brackets (P.B.) and the complete set of constraints for the theory of interaction of gravity (expressed by the 16-component fourleg field) with the Dirac electron field and the Maxwell field. The modified P.B. of the canonical conjugates to the fourlegs with each other and with the electron field variables do not vanish. As expected, besides the primary and the secondary constraint related to gauge invariance, there are four primary and four secondary constraints related to invariance under coordinate transformations, and six primary but no secondary constraints related to invariance under fourleg rotations. We are now investigating the quantization of the theory, using coordinate conditions and fourleg conditions as a tool, which should be eliminated (like the Lorentz condition in gauge-independent quantum electrodynamics[2]) in the final formulation of the theory according to the ideas of Bergmann and Goldberg.[3]

* Supported in part by the National Science Foundation.
[1] F. J. Belinfante, Bull. Am. Phys. Soc. Ser. II, 1, 46 (1956).
[2] F. J. Belinfante and J. S. Lomont, Phys. Rev. **84**, 541 (1951).
[3] P. G. Bergmann and Irwin Goldberg, Phys. Rev. **98**, 531 (1955).

N11. Divergence-Free Interaction of an Electron with Photons. MARCEL WELLNER, *Princeton University* (introduced by E. P. Wigner).—A formulation of quantum electrodynamics, needing no renormalization, is proposed in the case of one Dirac electron interacting with a quantized photon field. Physical states are represented by Fock vectors, depending on as many sets of space-time variables as there are particles, one set X being the electron coordinates. Creation and annihilation operators $A^{\pm\mu}(X)$ for photons are defined explicitly for all X without the help of a differential equation. These $A(X)$ are similar but not identical to the conventional free-field operators. The Dirac equation, where the $A(X)$ occur in the customary way, is required for the state vector with respect to the X. Transition amplitudes are computed from a scalar product involving integration over a space-like surface for each photon and over space-time for the electron. All calculations made so far (by expansion of the state vector in powers of e) have yielded the standard results of renormalized field theory. Preliminary calculations strongly indicate the possibility of extending the present formalism so as to cover many-electron problems and pair production.

N12. Generalized Lagrange Formalism and Quantization Rules.* PETER HAVAS, *Lehigh University.*—It was shown recently[1] that even if a set of equations $G_i=0$ is not derivable from a variational principle, there might exist an equivalent set $f_iG_i=0$, obtainable with the help of "integrating factors" f_i, which is so derivable. The general problem of equivalent sets has been investigated. It was found that for any set $G_i=\dot{q}_i+g_i(q,t)=0$ there always exist equivalent systems $\Sigma f_{ik}(q,t)G_k=0$ which are the Euler-Lagrange equations of a variational principle. As any system of differential equations is equivalent to a system of first-order equations, this implies that any system of nth order ordinary differential equations which may be solved algebraically for the nth order derivatives

is derivable from a Lagrangian. In particular this is the case for Newton's equations of motion with arbitrary velocity-dependent forces. For a given set of equations many different Lagrangians exist; quantization by any of the presently available rules (often thought to be as general as the classical formalisms of Lagrange or Hamilton) is either impossible or ambiguous. Some implications will be discussed.

* Research supported in part by the J. S. Guggenheim Memorial Foundation and by the A. F. Office of Scientific Research.
[1] Peter Havas, Phys. Rev. **83**, 224, 1951; Nuovo cimento (to be published).

N13. A Formula for the Entropy in Terms of the Molecular Distribution Functions. M. S. GREEN AND R. E. NETTLETON, *National Bureau of Standards.*—An expression proposed by Stratonovich[1] for the entropy in a subvolume V of an infinite spatially uniform fluid is used to derive a formula for the entropy in terms of the molecular distribution functions. This formula is expressed in terms of functions which are linear sums of the potentials of average force. The condition that the entropy be an extremum yields a set of integral equations for the equilibrium forms of these functions; and these equations are proved consistent with the requirement that the equilibrium probability of occurrence of a given number of particles in V in a given configuration be given by the grand canonical ensemble. From the integral equations for the distribution functions differential equations have been derived which are identical with the corresponding expressions obtained from the Born-Green hierarchy.

[1] R. L. Stratonovich, Soviet Phys. **1**, 254 (1955).

N14. A Statistical Mechanics of Biologically Associated Species. EDWARD H. KERNER, *University of Buffalo.*—A system of differential equations proposed by Volterra, describing the variation in time of the populations N_r of interacting species in a biological association, admit a Liouville's theorem (when $\log N_r$ are used as variables) and a universal integral of "motion." Gibbs' microcanonical and canonical ensembles can then provide a thermodynamic description of the association in the large. The "temperature" measures in one number common to all species the mean-square deviations of the N_r from their average values. There are several equipartition theorems, susceptible of direct experimental test, a theorem on the flow of "heat" (the conserved quantity in an isolated association) between two weakly coupled associations at different temperatures, a Dulong-Petit law for the heat capacity, and a second law expressing the tendency of an association to decline into an equilibrium state of maximal entropy. The analog of the Maxwell-Boltzmann law is a distribution of intrinsic abundance for each species which has been successfully used by ecologists for interpreting experimental data. A true thermodynamics develops upon introducing the idea of work done on an association through a variation of the variables (such as physical temperature) defining the physical and chemical environment. An ergodic theorem is suggested by the agreement of ensemble and time averages in the one case where the latter may be found explicitly.

N15. On the Hydrodynamical Model in Diabatic Flow of the Quantum Mechanics. M. Z. v. KRZYWOBLOCKI, *University of Illinois* (introduced by R. D. Hill).—Madelung presented an interpretation of quantum theory equations in hydrodynamical form. In his approach the fluid in question is an inviscid, nonheat conducting, compressible fluid. A diabatic flow can be thought of as a flow of a perfect, inviscid, nonheat conducting fluid, with heat addition or subtraction by means of sources or sinks distributed in flow field. In the present note the author generalizes Madelung's interpretation to diabatic flows.

SATURDAY MORNING AT 9:30

Social Sciences 122

(V. L. TELEGDI presiding)

Scattering of Nuclei and Neutrons; Photoneutrons

P1. Scattering of Protons by Helium between 11.6 Mev and 17.8 Mev.* KARL W. BROCKMAN, *Princeton University.*—In order to fill the gap between previous measurements of the differential cross section for the scattering of protons by Helium at 9.48 Mev[1] and at 17.45 Mev, the cross section has been measured at the following energies and laboratory angles. At 17.84, 16.24, and 15.05 Mev, measurements were made at 10 angles spaced every 15° between 30° and 165°, at 13.30 Mev at 9 angles between 30° and 150°, and at 11.65 Mev at 7 angles between 30° and 120°. The first three energies were obtained by varying the operating parameters of the Princeton cyclotron, and the latter two by allowing the protons to spend some of their energy in absorbers. Fairly standard techniques were used to measure the scattering by a gas target with particle detection by a NaI scintillation counter. The relative accuracy of the cross section, angle-wise and energy-wise, should be of the order of counting statistics (1%−1.5%); the absolute accuracy is believed to be about 2.5%. Progress on the analysis of the data by nuclear phase shifts will be reported.

* This work was supported by the U. S. Atomic Energy Commission and the Higgins Scientific Trust Fund.
[1] T. M. Putnam, Phys. Rev. **87**, 932 (1952).

P2. Elastic Scattering of 40-Mev Protons from He^4.* MORTON K. BRUSSEL AND JOHN H. WILLIAMS, *University of Minnesota.*—Absolute differential cross-section measurements have been made in the angular interval 5° to 146° cm for the elastic scattering of 40-Mev protons by He^4. The first two sections of the Minnesota Linac were used as proton source. Protons scattered from purified He were detected in NaI scintillation crystals. Data were taken with two different pieces of apparatus. For intermediate and large scattering angles, the detecting apparatus allowed an angular resolution to ±0.5°. For angles less than 20°, observations were made at 1° intervals with resolutions of ±0.3°, with apparatus specially constructed to observe small angle proton-proton scattering.† The features of the variation of cross section with angle are: following the predominant Coulomb scattering at low angles, one sees a pronounced minimum at 9.5° (cm angles), a maximum at 17.5°, a minimum at 115°, and a slow increase to the largest angle observed. Analysis of the data using an optical model treatment is being undertaken.

* Supported in part by the U. S. Atomic Energy Commission.
† Courtesy of L. Johnston and D. Swenson.

P3. Analysis of the Elastic Scattering of Protons from C^{12}.† D. ZIPOY, *University of Minnesota.*—A phase-shift analysis of three resonances found in the $C^{13}(pp)C^{13}$ reaction[1] has recently been completed. The method used was to find first the off-resonant phase shifts which was done by using three phase

shifts corresponding to $L=0$, 1, 2, and finding their values at scattering angles corresponding to the roots of the first- and second-order Legendre polynomials. To further adjust these phase shifts, a Taylor expansion was made about the foregoing values. A least-squares fit was then obtained at five scattering angles. The next step was to calculate the maximum minus the minimum cross sections, in the neighborhood of a resonance, using different level parameters. The criterion used was that the calculated values had to be as large or larger than the experimental value; this eliminated most of the choices of the resonant parameters. Of the remaining possibilities, the most likely assignments were: at 9.39-Mev excitation in N^{14}, $J=1^-$; at 9.51 Mev, $J=3^-$; at 9.72Mev, $J=1^+$. Previously, in a $C^{13}(p\gamma)N^{14}$ reaction,[2] a level at 9.49 Mev had been reported which had possible spin assignments of $J=1$ or 2.

† This work supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Zipoy, Famularo, Freier, Bull. Am. Phys. Soc. Ser. II, 1, 9 (1956).
[2] Woodbury, Day, and Tollestrup, Phys. Rev. **92**, 1199 (1953).

P4. Differential Cross-Section Measurements for the Elastic Scattering of Protons by N^{14}.† C. R. Bolmgren, G. D. Freier, J. G. Likely, and K. F. Famularo, *University of Minnesota.*—Further measurements[1] of the differential cross section for the elastic scattering of protons by N^{14} have been made in the energy range from 1.5 to 3.5 Mev at scattering angles of 39°14′, 54°44′, 90°, 125°16′, and 140°46′ in the center-of-mass coordinate system using a differentially pumped gas target. The probable error in the values of the cross section is about 4 to 5%. Pronounced anomalies in the cross section occur at laboratory proton energies of 1.55, 1.74, 1.905, 2.36, 2.49, 3.20, and 3.40 Mev, with a probable error in these energies of 0.01 Mev. The anomaly at 3.40 Mev indicates a previously unreported level in O^{15*} at about 10.5 Mev. The magnitude of the off-resonance cross section at 140°46′ is about four times, at 125°16′ about three times, and at 90° about two times that which would result from pure Rutherford scattering. At 54°44′ the off-resonance cross section differs from the Rutherford cross section over most of the energy range by less than 5%, while at 39°14′ the cross section is generally 10 to 20% below the Rutherford cross section.

† This work supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Webb, Li, and Fowler, Phys. Rev. **92**, 1084 (A) (1953); Ferguson, Clarke, Gove, and Sample, Preliminary Report PD-261, Atomic Energy of Canada Limited, Chalk River Project (1956); G. W. Tautfest and S. Rubin, Phys. Rev. **103**, 196 (1956); Bashkin, Carlson, and Jacobs, Bull. Am. Phys. Soc. Ser. II, 1, 212 (1956).

P5. Optical Model Analysis of 10-Mev Proton-Nucleus Scattering.* A. E. Glassgold, W. B. Cheston, M. L. Stein, S. Schuldt, and G. W. Erickson, *University of Minnesota.*—An optical model scattering program for the nonrelativistic scattering from an arbitrary complex central potential has been formulated for computation on the UNIVAC scientific computer.[1] Hintz's data[2] on 10-Mev proton-nucleus scattering have been analyzed using Saxon's potential.[3] Only three of the four parameters in this model are essential in obtaining good agreement with experiment. These are VR^2, W, and a. At this energy, moreover, there is more than one set of acceptable parameters. Some general statements will be noted concerning the dependence of the cross section on the foregoing parameters.

* Supported in part by U. S. Atomic Energy Commission.
[1] The authors are indebted to the Sperry-Rand Corporation for the use of their St. Paul computing facilities.
[2] N. Hintz, Bull. Am. Phys. Soc. **30**, 10 (1955).
[3] R. D. Woods and D. S. Saxon, Phys. Rev. **95**, 577 (1954).

P6. Optical Model Analysis of 40-Mev α-Nucleus Scattering.* W. B. Cheston, A. E. Glassgold, M. L. Syrin, S. Schuldt, and G. W. Erickson, *University of Minnesota.*—Employing a program developed for the UNIVAC scientific computer,[1,2] analysis of the experimental data of Igo *et al.*[3] on 40-Mev elastic α-nucleus scattering has been attempted. It is possible to obtain fits[4] to the experimental data using an optical model potential of the form first employed by Saxon *et al.*[5] in the analysis of elastic p-nucleus scattering. Variations in the predicted optical model cross section with changes in the model parameters will be discussed. The relationship between the results of the optical model and semiclassical models[6] used in analysis of α-scattering data will be presented.

* Supported in part by the U. S. Atomic Energy Commission.
[1] The authors are indebted to the Sperry-Rand Corporation, St. Paul, Minnesota, for use of their computing facilities.
[2] N. Hintz, Bull. Am. Phys. Soc. **30**, 10 (1955).
[3] Igo, Wegner, and Eisberg, Phys. Rev. **101**, 1508 (1956).
[4] Similar results have been obtained by G. Igo (private communication).
[5] R. D. Woods and D. S. Saxon, Phys. Rev. **95**, 577 (1954).
[6] See, for example, C. Porter, Phys. Rev. **99**, 1400 (1955).

P7. Elastic Scattering of 3.1-Mev Polarized Neutrons.* F. L. Hereford, B. M. McCormac, M. F. Steuer, and C. D. Bond, *University of Virginia.*—Partially polarized neutrons were produced by bombardment of a thick deuterium target by 750-kev deuterons.[1] Neutrons (mean energy ≈3.1 Mev) emitted at c.m. angle 53° (polarization, $P_n \approx 11\%$) were collimated and scattered in Be, C, Zr, and Pb. Differentially biased stilbene scintillation counters simultaneously detected neutrons elastically scattered to the right and left in the plane containing the $D(d,n)He^3$ reaction products. The ratio R of right-to-left scattered intensities was observed for a number of scattering angles between 40° and 135°, and the asymmetry,[2] $P_nP_{sc}(\theta)=1-R/1+R$, was computed therefrom (P_{sc} = polarization of the scatterer). For Be and C the angular dependences of the asymmetries showed strong $\sin 2\theta$ components. The Pb scatterer yielded a more complex angular variation; and Zr showed no asymmetry (± 0.1) over the range of scattering angles studied.

* Supported jointly by the U. S. Atomic Energy Commission and the Office of Ordnance Research.
[1] Meier, Scherrer, and Trumpy, Helv. Phys. Acta **27**, 277 (1954).
[2] See, for example, J. V. Lepore, Phys. Rev. **79**, 137 (1950).

P8. Scattering of 4.4-Mev Neutrons at 90° by Fe, Co, Ni, and Pb.† J. B. Weddell, *Westinghouse Research Laboratories.*—The spectra of neutrons scattered at 90° by iron, cobalt, nickel, and lead have been measured, for 4.4-Mev incident neutrons, by the proton recoil nuclear emulsion technique. The iron measurement is a repetition, under superior conditions, of an earlier experiment.[1] Differential cross sections for elastic scattering and for inelastic scattering with the scattered neutron energy above 0.8 Mev, are (in mb/sterad):

Element	$\sigma_{el}(90°)$	$\sigma_{in}(90°)$
Fe	32 ± 5	32 ± 10
Co	50 ± 10	44 ± 12
Ni	32 ± 5	20 ± 7
Pb (tentative)	125 ± 25	68 ± 23

Cross sections will be given for inelastic scattering processes involving individual energy levels. The results will be compared to predictions of an optical model with diffused surface.[2]

† Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Jennings, Weddell, Alexeff, and Hellens, Phys. Rev. **98**, 582 (1955).
[2] W. S. Emmerich and H. Amster, Physica (to be published).

P9. Elastic Scattering of 14-Mev Neutrons.* P. J. Dolan, H. A. Fincher, P. J. Kenny, S. Berko, and W. D. Whitehead, *University of Virginia.*—Previous experimental reports[1] and recent computations using various optical model parameters[2] show the need for more data on diffraction scattering of 14-Mev neutrons, particularly in the backward direction. An angular distribution apparatus has been built consisting of a $(2\text{–}3)\times10^{-9}$ sec resolving time coincidence circuit measuring (n,α) coincidences from the (d,t) reaction. The neutron beam is thus "collimated" to various shapes depending on the shape of the α counter (4–5 mil plastic scintillator). A slow triple coincidence circuit allows α pulse-height selection and neutron integral discrimination. Preliminary angular distribution data has been taken at 3° intervals from 17° to 140° for C, Al, Cu,

and Pb, and will be presented as a function of neutron energy bias and size of scatterer.

* Supported jointly by the U. S. Atomic Energy Commission and the Office of Ordnance Research.
[1] J. H. Coon and R. W. Davis, Phys. Rev. **94**, 785 (1954); W. G. Cross and R. G. Jarvis, Phys. Rev. **99**, 621 (1955); J. O. Elliot, Phys. Rev. **101**, 684 (1956).
[2] Culler, Fernbach, and Sherman, Phys. Rev. **101**, 1047 (1956); Bjorklund Fernbach, and Sherman, Phys. Rev. **101**, 1832 (1956).

P10. Photoneutron Thresholds for Germanium, Rubidium, and Hafnium. R. TOBIN AND J. MCELHINNEY, *Naval Research Laboratory.*—Photoneutron thresholds for several of the isotopes of germanium, rubidium, and hafnium have been measured using the x-ray beam from the NRL 20-Mev betatron and a neutron detection system. The resulting data were analyzed for changes in the rate of increase in yield as a function of energy. The energies at which these occurred were then associated with the threshold for photoneutrons from a particular isotope. The energy assignments of these thresholds are based on a calibration of the betatron x-ray beam using the mass values of fluorine and oxygen and the reactions $F^{19}(\gamma,n)\times F^{18}$ and $O^{16}(\gamma,n)O^{15}$. These assignments are

Isotope	Threshold (Mev)
Ge^{73}	7.34, ±0.15*
	7.66, ±0.15
Rb^{85}	9.26, ±0.15
Rb^{87}	10.14, ±0.15
Hf^{177}	6.70, ±0.09
Hf^{179}	6.52, ±0.12

* Interpreted as the thresholds for the formation of the 0.83 Mev and the 1.46-Mev excited levels in Ge^{73}.

P11. Photoneutrons from Lead.* M. ELAINE TOMS, *Naval Research Laboratory,* AND WILLIAM E. STEPHENS, *University of Pennsylvania.*—The energy and angular distribution of photoneutrons from lead has been determined using recoil protons in nuclear emulsions. A 1.248-g truncated sphere of lead was bombarded by 7140 roentgens of 23-Mev bremsstrahlung x-rays produced by the University of Pennsylvania betatron. Recoil protons lying within a square pyramid defined by ±15° to the direction of the neutrons were accepted for measurement. This investigation differs from that of Dixon[1] in that the bombarding energy was lower and that energy distributions at each angle are determined. Our results are similar to those of Zatsepina, Lazareva, and Pospelov for Bismith (γ,n), reported at the International Conference on Nuclear Reactions in Amsterdam, in that the higher energy neutrons are peaked about 90° to the beam.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] W. R. Dixon, Can. J. Phys. **33**, 785 (1955).

P12. Cross Section for Photodisintegration of Beryllium near Threshold.* D. R. CONNORS† AND W. C. MILLER, *University of Notre Dame.*—The neutron yield in the photodisintegration of beryllium has been measured from threshold to 2.100 Mev using the bremsstrahlung produced by the stopping of an electron beam in a thick gold target. The electron beam from our new, pressurized electrostatic generator was energy selected by our electrostatic analyzer with a resolution of 4 kev. An extrapolation of the square root of the neutron yield gave a value of 1.664±0.004 Mev for the threshold in excellent agreement with the result of Noyes, *et al.*[1] An analysis of the yield curve showed a large peak in the (γ,n) cross section just above threshold, indicating a level in beryllium at 1.70±0.05 Mev which can be photoexcited. The minimum ratio of the peak cross section to the value of the cross section between 1.75 and 1.97 Mev was found to be 200:1. Using the value[2] of the cross section at 1.81 Mev the peak cross section was found to be of the order of 100 mb. The width of this peak was found to be less than 50 kev. A shell model calculation of the disintegration process by C. Mast[3] indicates that the peak is due to a magnetic dipole transition to a low-lying level.

* Supported in part by the joint program of the U. S. Atomic Energy Commission and the Office of Naval Research.
† Now at Westinghouse Atomic Power Division.
[1] Noyes, Van Hoomissen, Miller, and Waldman, Phys. Rev. **95**, 396 (1954).
[2] Russell, Sachs, Wattenberg, and Fields, Phys. Rev. **73**, 545 (1948).
[3] C. Mast (private communication).

P13. Monoenergetic Neutron-Proton Coincidences from the Photodisintegration of Lithium.† R. WEINSTEIN, S. OZAKI, AND A. WATTENBERG, *M. I. T.*—A study of the velocity spectrum of photoneutrons produced in coincidence with protons from a lithium target has been made using the 320-Mev bremsstrahlung beam of the M. I. T. synchrotron. The neutron time of flight was measured by means of an eleven-channel chronotron, and the proton energy by means of a two counter proton telescope. The purpose of the experiment was to measure the momentum distribution of the center of mass of quasi-deuterons in the lithium nucleus in a more direct manner than attempted previously.[1] Preliminary results have been obtained for the quasi-deuteron momentum spectrum. Results appear to be in agreement with a Gaussian single-particle momentum, but a 0° Fermi distribution is ruled out. The equivalent single-particle energy which gives the proper Gaussian is about 8 Mev. This is in agreement with previous results obtained by other methods.[1] The present method is of interest because it opens the possibility of careful measurements on the tail of the momentum distribution. It is in this region that one might expect to find deviations from predictions based upon an extreme single-particle model.

† This work has been supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Odian, Stein, Wattenberg, Feld, and Weinstein, Phys. Rev. **102**, 837 (1956).

SATURDAY MORNING AT 9:15

Eckhart 133

(E. A. COOMES presiding)

Invited Paper

Q1. Recent Developments in Static Electrification. D. J. MONTGOMERY, *Michigan State University.* (30 min.)

General Physics

Q2. Structure of Liquid Selenium and Liquid Tellurium.† R. BUSCHERT, I. G. GEIB, AND K. LARK-HOROVITZ, *Purdue University.*—The x-ray scattering curves from a free surface of liquid selenium at 235°C and 310°C, and from amorphous selenium, were measured with a proportional counter spectrometer for both copper and molybdenum monochromatic

radiations. A balanced filter eliminated the Se K radiation excited by the molybdenum radiation. Fourier analysis of the corrected intensity function for Se at 235°C gave the radial distribution function showing 2.3 nearest neighbors at a distance of 2.36 A and an additional major peak at 3.7 A, indicating the presence of chains or rings. The Finbak electron distribution functions, $\sigma(r)$, have been evaluated for liquid Se at 235°C and 310°C and amorphous Se. All three curves show major peaks at 2.35 and 3.7 A and small peaks at greater r, showing that the short-range distribution has not changed. The previous measurements[1] for tellurium at 465°C have been extended to 610°C. Although the distribution functions show significant changes as temperature is increased, the persistence of the first peak at 2.9 A indicates that there are still chains (or rings) present at 610°C.

† Work supported by a Signal Corps contract.
[1] Buschert, Geib, and Lark-Horovitz, Phys. Rev. **98**, 1157 (A) (1955).

Q3. Quadrupole Coupling Constants of Nitryl Chloride.* LORIMER CLAYTON, QUITMAN WILLIAMS, AND T. L. WEATHERLY, *Georgia Institute of Technology.*—The $J=2\rightarrow3$ and $J=3\rightarrow4$ transitions of nitryl chloride (NO_2Cl) have been observed in the region 25.3 to 37.1 kmc, and quadrupole coupling constants have been determined from the hyperfine structure. Only the splittings due to the chlorine nucleus are resolvable. A "maximum likelihood" fitting process gives the following couplings: NO_2Cl^{35}—$\chi_{aa}=-94.7$ mc, $\chi_{bb}=52.2$ mc, $\chi_{cc}=42.5$ mc; NO_2Cl^{37}—$\chi_{aa}=-74.6$ mc, $\chi_{bb}=41.1$ mc, $\chi_{cc}=33.5$ mc. The statistical procedure employed insures proper weighting of each independent line-frequency measurement and yields a determination that predicts the observed shifts of 50 lines with a standard deviation of 0.02 mc. Rotational constants are not yet known precisely. Levels antisymmetric in the identical oxygen atoms of the Y-shaped planar molecule[1] are absent, and the remaining allowed transitions afford only a weak determination of the rotational constants unless the approximation $I_a+I_b-I_c=0$ is imposed as an additional restriction. With or without this restriction, slight inconsistencies in the determination attributed to centrifugal distortion prevent simultaneous fitting of all observed transitions. When the $2\rightarrow3$ transitions are fitted, prediction errors are 0.1 to 0.6 mc for the $3\rightarrow4$ transitions and 0.25 mc for the lower-J transitions previously reported.[1]

* Sponsored by the Office of Ordnance Research, U. S. Army.
[1] D. J. Millen, and K. M. Sinnott, *Chemistry and Industry* (May 7, 1955), p. 538.

Q4. Dissociation Energies of the TaO and TaO_2 Molecules.* M. G. INGHRAM, J. BERKOWITZ,† AND W. A. CHUPKA, *Argonne National Laboratory.*—A mass spectrometric study[1] was made of the vapor effusing from tantalum Knudsen cells containing $Ta-Ta_2O_5$ and $Ta-ZrO_2$ mixtures at high temperature. The major gaseous species vaporizing from the $Ta-Ta_2O_5$ mixtures were TaO and TaO_2 molecules. The vapor above the $Ta-Zr\ O_2$ mixtures consisted mostly of TaO and ZrO molecules produced by the reaction $Ta(s)+Zr\ O_2(s)\rightarrow TaO(g)+ZrO(g)$. The partial pressures of these gases and their temperature dependence were measured. A thermodynamic treatment of the data yielded values of ΔH for the reactions by which these molecules are formed. These values were combined with known thermochemical data to give $D_0(TaO)=8.5\pm0.3$ ev and $D_0(TaO_2)=15.5\pm0.3$ ev.

* Work supported partly by a grant from the National Science Foundation and partly by the U. S. Atomic Energy Commission.
† University of Chicago.
[1] W. A. Chupka and M. G. Inghram, J. Phys. Chem. **59**, 100 (1955).

Q5. Optical Absorption by UO_{2+x} Film.* G. H. WINSLOW, R. J. THORN, AND R. J. ACKERMANN, *Argonne National Laboratory.*—Films of UO_2 were evaporated onto fused quartz and annealed in a background pressure of 10^{-6} mm Hg at 950°C for two weeks. Within 12 hours after removal from the vacuum, absorption curves were run on a Cary spectrophotometer between 210 mμ and 800 mμ. Subsequent annealing in hydrogen produced no significant change. Fifteen films from 132 mμ to 280 mμ thick were used to determine optical constants. Thickness was determined from alpha count and interferometric measurement of thickness of three films.[1] The absorption coefficient is very small down to 650 mμ, reaches $1.36\times10^5\ cm^{-1}$ at 320 mμ, has a minimum at 245 mμ, and then increases rapidly. The first-mentioned peak appears to be double. The less certain values of refractive index show a maximum of 2.7 at 650 mμ, a minimum of 1.2 at 375 mμ. Heating in oxygen pressures of 3×10^{-5} mm Hg to 4×10^{-4} mm Hg up to 960°C causes decreased absorption in 340 mμ $<\lambda<480$ mμ, increased absorption elsewhere. Growth of a small peak at about 600 mμ with increased low-temperature (130°C) oxidation is indicated. Prolonged heating at 980°C and 4×10^{-4} mm Hg of oxygen removes the film without apparent damage to the substrate.

* Based on work performed under the auspices of the U. S. Atomic Energy Commission.
[1] Preparation and photography for thickness measurements were done by T. E. Hopkins under the direction of T. E. Phipps at the University of Illinois.

Q6. Energy Transfer and Equilibrium in Hydromagnetic Turbulence.* ROBERT H. KRAICHNAN, *New York University.*—The nonlinear interaction among spatial Fourier modes in incompressible hydromagnetic turbulence is a sum of overlapping, individually conservative *triangle* interactions, each involving three modes. It is hypothesized that phase correlations among any small group of modes result wholly from *direct* interaction, defined as those triangle interactions involving no modes outside the group. Starting from a normal, independent zeroth order distribution, cross moments in the statistical distribution of the amplitudes of modes within a group are constructed by introducing the direct interaction as a perturbation on the rest of the interaction, assuming that departure of the perturbed distribution from normality is small in a suitable sense. Triple correlations are thereby expressed in terms of quadratic correlations, producing closed equations for the latter which determine energy transfer rates and equilibrium spectra. The self-consistency and validity of the phase-correlation hypothesis and associated perturbation procedure are examined in relation to Reynolds' numbers. The theory described predicts an essential nonnormality of relationship between quadratic and quartic moments in the perturbed distribution. An argument independent of this theory is examined concerning whether normal relationship between these moments does not lead to ambiguities and inconsistencies in describing energy transfer among modes.

* This research was supported by the Geophysics Research Directorate, A. F. Cambridge Research Center.

Q7. Secondary Beryllium Ions Produced by Ion Bomabrdment.* H. E. STANTON, *Argonne National Laboratory.*—Ions originating in a solid beryllium target under bombardment by positive ions have been investigated with a mass spectrometer and their energies analyzed. It has been found that important fractions of the emitted ions of the target material have energies too high to be interpreted as being in thermodynamic equilibrium. It will be shown that a Maxwell-Boltzmann distribution for 14 000°K does not adequately fit the observed distribution of ionic energies, and that a theory involving ionic or atomic impacts may be required. The latter hypothesis is supported in part by observing ionic yields as a function of the mass number of the impinging primary ions. Curves showing the variation in the intensity of ions of beryllium as a function of the atomic masses of the bombarding ions formed from some of the premanent gases will be presented. The spectrometer used in these measurements is a modified form of a 12-in. double-focusing instrument and permits the energy analysis of the secondary ions. It will be described briefly.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

Q8. Pulsed Electroluminescent Panel. ARTHUR BRAMLEY, *Allen B. DuMont Laboratories, Inc.*—The use of electroluminescent phosphors in scanned display devices needs data on buildup and decay of electroluminescent phosphors. These measurements utilized an electroluminescent panel with a green DuPont phosphor and a set of parallel conducting strips on each side. The strips of set I were much wider than those of set II and enclosed a subset of II. Light output for a 2-kc sine wave at 600 v, peak to peak, was half that for a square wave with a 2-kc repetition rate, 250 μsec duration at 600 v peak to peak. Decreasing pulse length at 600 v from 250 to 0.9 μsec left peak light output and light cutoff of 310 v unchanged if resistance of conducting strips remained less than impedance of capacitor between strips. Total light output increased linearly with frequency from 2 to 10 kc for a 25-μsec pulse. The phosphor decay period was 250 μsec. A linear scanned panel has the advantage that N strips of information require only $2\gamma N$ switches or even less with binary counter-drive input. This type of panel combined with line selector light amplifier is promising as high-speed scan plotting board.

Q9. Drift Velocity and Average Energy of Electrons in Noble Gases.* J. C. BOWE, *Argonne National Laboratory.*—The drift velocity of electrons has been measured in purified neon, argon, krypton, and xenon, as a function of E/p ranging from values of 0.02 v/cm/mm Hg to breakdown. The velocity is determined by measuring the time duration of the current pulse in a parallel plate chamber enclosed in an all-metal, helium-tight system. The results for neon and argon are in excellent agreement with the calculated curves of Graham and Ruhlig[1] and lie lower than any previously published measurements. However, for argon, agreement is had with D. D. Errett[2] from the lowest values of E/p to 1.5. Beyond this point, the present values are lower by as much as 10%. There seem to be no published data with which to compare the results in krypton and xenon. The Townsend energy factor, which is a measure of the average electron energy, can be determined by measuring the difference in the time dispersion between the trailing and leading edges of the current pulse on the assumption that this difference is due to diffusion of the electron cloud. Results of an attempt to do this will be presented.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] W. J. Graham and A. J. Ruhlig, Phys. Rev. **94**, 25 (1954).
[2] D. D. Errett, Ph.D. thesis, Purdue University (unpublished) (1951).

Q10. Stopping Powers of Various Gases for Helium and Lithium Ions.* S. K. ALLISON, M. T. BURGY, AND C. S. LITTLEJOHN, *Argonne National Laboratory and University of Chicago.*—Weyl's mesaurement[1] of $dE\,dx$ for helium ions in the gases hydrogen, helium, air, and argon extended from 0.100 to 0.450 Mev. The helium ion measurements have been extended to 0.900 Mev in H_2, He, and air, and, in the case of argon, to 4.2 Mev. dE/dx for helium in argon shows a broad maximum at about 0.850 Mev, where per atom per cm² of argon it is $(80\pm3)\times10^{-15}$ ev. Simple stopping power theory predicts that the stopping power for He^{++} should be four times that for protons of the same velocity. By comparing our stopping power results for helium ions in argon with those for protons in argon it is seen that the factor of four indeed applies for helium ions above 1.3 Mev, but that for lower kinetic energies it falls off as expected, due mainly to the increasing neutralization of He^{++} by electron capture. The stopping power of H_2, He, air, and argon for lithium-7 ions of kinetic energies 150–450 kev have been measured.

* Work supported in part by the U. S. Atomic Energy Commission.
[1] P. K. Weyl, Phys. Rev. **91**, 289 (1953).

Q11. High-Frequency Multipacting Modes.* ALBERT J. HATCH† AND H. BARTEL WILLIAMS, *New Mexico College of A. and M. A.*—The higher order modes of the multipacting mechanism of low pressure high-frequency gaseous breakdown (secondary electron resonance) have been studied theoretically and experimentally. A new formulation of the theory for the $(2n-1)$ $\frac{1}{2}$-cycle electron transit time modes $(n=1,2,3\cdots)$ has been developed. Theoretical breakdown voltage V is plotted as a function of the product of frequency times electrode separation fd for the $\frac{1}{2}$- through the $\frac{9}{2}$-cycle modes. Each mode is represented by a region limited by lower and upper electron arrival phase angles and energies. Breakdown voltages have been measured between parallel alclad electrodes in air at 2×10^{-3} mm Hg pressure over the fd range of 105 to 742 MC cm/sec. The breakdown data show the typical $\frac{1}{2}$-cycle multipacting cutoff at 105 MC cm/sec plus a previously unreported $\frac{3}{2}$ cycle cutoff at approximately 470 MC cm/sec. The $\frac{3}{2}$-cycle cutoff is indicated by a sharp dip in the breakdown curve and agrees fairly well with theory. Between the $\frac{1}{2}$- and $\frac{3}{2}$-cycle cutoffs $V\propto(fd)^2$; in the immediate vicinity of the $\frac{3}{2}$-cycle cutoff, and at all higher values of fd, $V\propto fd$. The observability of the $\frac{3}{2}$-cycle cutoff appears to be critically dependent on electrode surface conditions.

* Work supported by the Bureau of Ordnance, U. S. Navy.
† Now at Argonne National Laboratory.

Q12. Arc Initiated Discharge in Magnetic Field in High Vacuum. I. Ionic Centrifuge Type of Discharge. J. SLEPIAN, *Westinghouse Research Laboratories.*—A short arc between electrodes in a parallel magnetic field, set in the middle of a high vacuum tank, gives off a current to the tank wall positive or negative and not limited in any way by space charge. With a 100-amp central arc we have obtained 10 amp of ions to the walls (and 5 amp of electrons) with no strain upon the vacuum, and at a voltage too low for emission of electrons by condensing ions. Study shows that the condition for space-charge limitation to a very low value, holding for a source limited to carriers of one sign only, fails completely when the source has carriers of both signs. A discharge occurs with cylinder insulated and at a potential of $-(e/8mc^2)H^2r^2$ esu receiving both ions and electrons, but with the end walls energized to a still higher voltage and receiving positive ions alone. The ions (and electrons) have a random energy at each point of the discharge equal to the circumferential energy of mean motion of the positive ions, so that this type of discharge is ineffective for isotope separation. The new type of discharge, the magnetoionic expander-type is well suited for that.

SATURDAY MORNING AT 9:30

Oriental 272

(J. H. WILLIAMS presiding)

General Nuclear Physics; Nuclear Instrumentation

R1. Spin and Magnetic Moment of the 1.7-hr Metastable State of In^{113}.† WILLIAM J. CHILDS AND LEONARD S. GOODMAN, *Argonne National Laboratory.*—The atomic beam magnetic resonance technique[1] was used to measure the nuclear spin and the magnitude of the magnetic dipole moment of the 390 kev, 1.7-hr metastable state of In^{113}. Using an In^{115} beam for

magnetic field calibration, the rf frequency for refocusing In^{113m} atoms was measured for several intensities of the "C" field. The results indicate that the nuclear spin of In^{113m} is $\frac{1}{2}$, and that the magnitude of the magnetic dipole moment is 0.217 ± 0.002 nuclear magnetons. Further measurements are expected to make possible a determination of the sign of the magnetic moment.

† Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] L. S. Goodman and S. Wexler, Phys. Rev. **97**, 242 (1955).

R2. Spin of Thallium Isotopes 198m, 199, and 204.* G. O. Brink, J. C. Hubbs, W. A. Nierenberg, and J. L. Worcester, *University of California, Berkeley.*—The nuclear angular momenta of three unstable thallium isotopes have been determined by atomic beam methods applied to the $^2P_{\frac{1}{2}}$ state of thallium. The results are that the spin of 1.8-hr Tl^{198m} is 7, the spin of 7.2-hr Tl^{199} is $\frac{1}{2}$, and the spin of 3-yr Tl^{204} is 2. The two neutron-deficient isotopes are produced by α-particle bombardment of Au^{197} in the Berkeley 60-in. cyclotron, and Tl^{204} is produced by neutron activation of stable thallium. Beam exposures at spin 7 show a 1.8-hr activity building into a 5.3-hr Tl^{198} activity,[1,2] while those at spin $\frac{1}{2}$ show a single 7.2-hr Tl^{199} activity.[1] The mass assignment for spin 2 is made from the known activation cross sections[3] of Tl^{203} and Tl^{205} coupled with the observation that the size of the spin 2 resonance accounts for substantially all the sample activity. In addition, a search made for gamma rays has had negative results, as have those made by other observers.[4]

* This work supported by the U. S. Atomic Energy Commission.
[1] M. C. Michel, "Separation and assignment of radioactive isotopes," Ph.D. thesis, UCRL-2267 (1953).
[2] Paksell, Michel, and Bergstrom, Phys. Rev. **95**, 999 (1954).
[3] D. Hughes and J. Harvey, "Neutron cross sections," BNL-325 (1955).
[4] M. Goldhaber and R. D. Hill, Revs. Modern Phys. **24**, 179 (1952).

R3. The Spin of 7.1-Day Cs^{132}.* W. A. Nierenberg, J. C. Hubbs, H. A. Shugart, H. B. Silsbee, and P. O. Strom, *University of California, Berkeley.*—The spin of 7.1-day Cs^{132} has been measured and found to be $I=2$. The isotope was prepared by $p-n$ bombardment of Xe^{132}, and the spin was measured by conventional atomic beam methods. The value of $I=5/2$ for 9.6-day Cs^{131} obtained by Bellamy and Smith[1] was confirmed due to the $p-n$ reaction on Xe^{131}. The value of $I=\frac{1}{2}$ for Cs^{129} previously obtained by the $\alpha-2n$ reaction on I^{127} was confirmed due to the $p-n$ reaction on Xe^{129}. Values for the hyperfine structure constant of Cs^{132} will be given. The result of $I=2$ for Cs^{132} will be compared to the results $I=\frac{1}{2}$ for Cs^{127}, $I=\frac{1}{2}$ for Cs^{129}, and $I=1$ for Cs^{130} previously obtained by (α,kn) on I^{127}. The difficulties of explaining these results in terms of the current nuclear models will be discussed.

* Work supported by the U. S. Atomic Energy Commission and the Office of Naval Research.
[1] E. H. Bellamy and K. F. Smith, Phil. Mag. **44**, 33 (1953).

R4. Extraterrestrial Radiation from the H^3, He^3, and Li^6 Contents of Meteorites.*† E. L. Fireman,‡ *Brookhaven National Laboratory.*—Tritium is found in the recent meteorites, Norfork (1918) and Para de Minas (1934). None ($<10^4$ tritons/g) is found in the old meteorites, Charcas and Canyon Diablo. At their time of fall the tritium contents of Norfork and Para de Minas were 2×10^6 tritons/g and 6×10^5 tritons/g. Since meteorites are of extraterrestrial origin, the presence of H^3 in recent falls is direct evidence for the existence of radiation in extraterrestrial space. If the H^3 contents are combined with the measured H^3 production cross section for energetic protons on iron, intensities of 10 particles/cm^2 sec and 3 particles/cm^2 sec are obtained if the primaries have a $1/E^2$ energy distribution and a 1-Bev cutoff. The He^3 contents of Norfork and Para de Minas are measured to be 6.2×10^{-6} cc/g and 2.8×10^{-6} cc/g. The H^3 and He^3 contents combine to give these meteorites ages of 1.1×10^9 and 1.7×10^9 years. Measurements on six iron and five stone meteorites indicate that the He^3 contents are not proportional to the Li^6 contents. The average slow neutron flux therefore has been less than 1 neutron/cm^2 sec.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
† A more detailed description of this work together with the necessary acknowledgments and references is given in Brookhaven National Laboratory Report 2838.
‡ Present address: Smithsonian Astrophysical Observatory, Harvard College Observatory.

R5. 10.5-Mev Bremstrahlung Spectrum. C. P. Sargent, W. Bertozzi, and P. T. Demos, *M. I. T.*—A measurement as a function of electron energy of the yield of 2.9-Mev photoprotons from the 30-kev[1] wide 10.43-Mev excited state of N^{14} provides a measurement of the high-energy end of a 10.5-Mev bremstrahlung spectrum with 30-kev effective resolution. The measured spectrum is produced by the magnetically analyzed electron beam of the M.I.T. linear accelerator incident on a Ta target. The photoprotons are produced in one atmosphere of N_2 gas and are detected with a thin (65 mg/cm^2) CsI(Tl) crystal. For purposes of comparison with theory the effective resolution is $3.5\pm0.5\%$ and is determined mainly by the width of the incident electron spectrum. The data are compared with that predicted by a spectrum $B(E_0,k,\eta)=S(E_0,k)[1+\eta\{f(E_0,k)-1\}]^{\eta/|\eta|}$. S is the Schiff spectrum and $f=\beta^{-1}(1-e^{-2\pi z/137})/(1-e^{-2\pi z/137\beta})$ with β the velocity of the scattered electron and $z=73$. Preliminary result of the measurement is $\eta=-0.5\pm1.2$.

[1] H. B. Willard (private communication).

R6. Neutron and Proton Distributions in Lead.* J. W. Cronin, A. Abashian, and R. L. Cool, *Brookhaven National Laboratory.*—Johnson and Teller proposed a model of the nucleus which predicts neutrons at larger radii than protons in nuclei with a neutron excess. High-energy pions can serve as a probe to measure such a difference. If the elementary cross sections $\sigma(\pi^-,p)$ and $\sigma(\pi^+,p)$ are quite different (as at 700 Mev), a difference in radial distributions will result in a difference in the total absorption cross sections for positive and negative pions. Absorption cross sections were measured by scintillation counter techniques at 700 Mev and at 1100 Mev where the elementary cross sections are nearly equal. Using the elementary pion-proton cross sections and a square-well nucleon distribution, the quantity $q=[\sigma(\pi^-)-\sigma(\pi^+)]/\sigma(\pi^+)$ has been calculated from the optical model for two nucleon distributions: (I) $r_n=1.3A^{\frac{1}{3}}\times10^{-13}$ cm, $r_p=r_n[Z/(A-Z)]^{\frac{1}{3}}$; (II) $r_n=r_p=1.3A^{\frac{1}{3}}\times10^{-13}$ cm. The results of the calculations and the experimental values of q are:

Energy	Model I	Model II	Experiment
700	-0.024	$+0.044$	$+0.050\pm0.011$
1100	$+0.034$	$+0.045$	$+0.017\pm0.012$

A comparison of the computed and measured values of q at 700 Mev, as well as the change in q from 1100 to 700 Mev, shows no evidence for larger neutron radii, contrary to the predictions of the proposed model.

* Work done under auspices of the U. S. Atomic Energy Commission.

R7. Nucleon Binding Energy Systematics for the 82-Neutron Region.* W. H. Johnson, Jr., and A. O. Nier, *University of Minnesota.*—A six-inch double-focusing mass spectrometer has been employed to determine, by the doublet method, 36 atomic masses in the region of the 82-neutron shell closure. These atomic masses, in the region $A=130$ to 154 and $Z=54$ to 63, have been measured with an accuracy of about ±0.075 mμ. By employing nuclear reaction Q values and total beta-decay energies, the atomic masses of 41 radioactive nuclei in this region have been calculated. From the resulting table of masses one can determine nucleon binding

energies with useful precision. The systematic behavior of these binding energies has been studied in greater detail than was previously possible. The neutron binding energy discontinuity at $N=82$, indicated by beta-decay energetics and reaction data, is now shown to be caused by a decrease in the binding energy of the neutrons beyond $N=82$. In addition, anomalies in the nucleon binding and pairing energies near $N=90$ indicate a change in nuclear structure. This change also has been observed in electric quadrupole systematics.

* This research supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

R8. The A^{40}, K^{41}, and He^3 Content of Iron Meteorites.* J. ZÄHRINGER† AND E. L. FIREMAN,‡ *Brookhaven National Laboratory*.—The A^{40} in iron meteorites can result from the spallation of iron nuclei by cosmic rays or from the decay of K^{40}. The cosmic ray produced A^{40} should be proportional to the He^3 content.[1] In meteorites with high K and low He^3 content an accurate $K^{40}-A^{40}$ age can be determined. The A^{40}, He^3, and K content of some iron meteorites have been measured by activating A^{40} to A^{41} and He^3 to H^3 [2] with slow neutrons and K^{41} to A^{41} with fast neutrons. In seven iron meteorites examined the A^{40} content ranged from less than 10^{-8} cc/g to 10^{-6} cc/g; the He^3 content ranged from less than 2×10^{-9} cc/g to 6×10^{-6} cc/g; and the K content ranged from less than 2×10^{-7} g/g to 10^{-5} g/g. The N'Goureyma iron meteorite had a high K content and a small He^3 content and therefore has negligible A^{40} from spallation. Its $K^{40}-A^{40}$ age is 4.8×10^9 years.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
† Supported by Deutsche Forschungsgemeinschaft.
‡ Present address: Smithsonian Astrophysical Observatory, Harvard College Observatory.
[1] W. Gentner and J. Zähringer, Z. Naturforsch. **10c**, 498 (1955).
[2] E. L. Fireman and D. Schwarzer, Brookhaven National Laboratory Report 2838.

R9. Radially Dependent Energy Losses in a Synchrotron.* G. K. O'NEILL, *Princeton University*.—A tentative method for injecting particles into a "storage-ring" guide field has been described.[1] It was noted that tapered energy loss foils of the type needed to allow injection would cause undamping of radial betatron oscillations. This note concerns the first-order quantitative effect of foils on synchrotron and radial betatron oscillations, under the physically reasonable assumptions of small energy loss compared to particle energy, small scattering, the foil gradient large compared to the (constant) guide field gradient. The betatron oscillation growth factor was found to be $A=\frac{1}{2}(n_f/(1-n))d\ln E/dt$ sec^{-1}, and the synchrotron growth factor $-A$. The combined betatron-synchrotron phase density is thus conserved, a qualitative result reported previously.[2] The conclusion is that linearly tapered foils would be effective in allowing irreversible injection but would be of no value in damping. A calculation generalized to arbitrary foil shapes and large energy losses has since been derived independently by another group and will be reported on at this meeting. Other methods of damping a stored beam have been suggested and will be described briefly.

* This work was supported by the U. S. Atomic Energy Commission and the Higgins Scientific Trust Fund.
[1] G. K. O'Neill, Phys. Rev. **102**, 1418(L) (1956).
[2] CERN symposium on High-Energy Accelerators (June, 1956) (to be published).

R10. Electron Injection in Betatrons. M. DANOS, *National Bureau of Standards*.—The influence of azimuthal field inhomogeneities on the capture of electrons in the equilibrium orbit at injection[1] was investigated. The NBS analog computer was utilized to calculate particle orbits in the linearized small amplitude approximation neglecting space-charge effects. The parameters varied were shape and time dependence of the inhomogeneity. The results show that injection over an extended time is possible and is limited in practice only by the obtainable shape and size of the injection pulse. This can be achieved by the combined effect of a steady-state field inhomogeneity (located at the gun and/or at 180°) and the adiabatic damping[2] if the field index n of the machine is not too close to $\frac{3}{4}$. The radial oscillations here are stable and only modulated in amplitude and phase in contrast to Baldwin's suggestion[1] that they are resonance-damped unstable oscillations and that pulsed inhomogeneities are required.

[1] G. C. Baldwin, General Electric Report 56-RL-1444 (unpublished).
[2] D. W. Kerst and R. Serber, Phys. Rev. **60**, 53 (1941).

R11. Hanford Crystal Spectrometer Automatic Equipment.* E. J. SEPPI, B. R. LEONARD, JR., AND W. J. FRIESEN, *General Electric Company*.—The Hanford crystal spectrometer has been equipped for the automatic taking and recording of neutron cross-section data. The outstanding features of this instrumentation are the program units for the angular positions and the sequence of spectrometer operations. Each of these units is based on the operation of a stepping switch which reads the desired program from coded plugs. This system was designed for the high versatility required for making multiple transmission measurements with the use of selective filters. As many as twenty-six operations can be coded into the sequence program for each angular position. The time intervals of the sequence program are coded into four different preset count intervals. The angular position program can be coded for different equal angular increments or for cyclic operation through eleven arbitrary angles. Data recording is made on an electric typewriter with a printing system nearly identical to that used at the M.T.R. crystal spectrometer.[1] Data obtained with this equipment which now firmly establish the existence of fission is the 1-ev resonance in plutonium-240[2] will be presented.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] G. L. Smith and L. G. Miller, Phys. Rev. **96**, 849 (1956).
[2] Leonard, Seppi, Friesen, and Kinderman, Bull. Am. Phys. Soc. Ser. II, **1**, 248 (1956).

R12. A Two-Dimensional Pulse-Height Analyzer.* M. BIRK, R. W. DETENBECK,† AND T. H. BRAID, *Princeton University*.—A two-dimensional analyzer classifies a coincidence event between two detectors according to both pulse heights. The events are sorted into "channels" covering a plane, instead of the linear array of the conventional analyzer. The pulse heights are measured by Wilkinson-type analyzers (A and B) gated by the coincidence signal. The event is recorded as a pair of binary numbers on paper tape (range 0–127). In reading out, the B numbers control the output from a relay pulser. These pulses are fed to a 99-channel analyzer so that each is displayed in the channel whose number is punched on the tape. The B pulse is read only if the A number falls within a range determined by a network of relays and switches. Maximum recording rate is 8/sec; read-out is at 10/sec. γ-ray spectra in coincidence with several inelastically scattered proton groups are being recorded in one run at total rates of 1 count/sec or less. Each spectrum is read out at 10/sec. The advantage is proportional to the number of spectra read out.

* Work supported by the U. S. Atomic Energy Commission and the Higgins Scientific Trust Fund.
† National Science Foundation Predoctoral Fellow during 1955–1956.

R13. Application of Liouville's Theorem in the Presence of Dissipative Forces.* K. R. SYMON, *University of Wisconsin*, P. STEHLE, *University of Pittsburgh*, AND D. B. LICHTENBERG, *Indiana University and Midwestern Universities Research Association*.—The density of particles that can be attained in an accelerator beam is limited by Liouville's theorem if the forces operating on the particles are Hamiltonian. If dissipative forces are present, the rate of change in a volume in phase space can be related to an integral over phase space of the

partial derivatives of the dissipative forces with respect to the momenta of the phase points. This result has been applied to the case of foils of matter placed in the path of a beam of particles. The compression of a volume in phase space is found to be comparable to the degradation of particle momenta in the foils, independent of the shape of the foils.

* Work supported by the National Science Foundation, Office of Naval Research, and U. S. Atomic Energy Commission.

SATURDAY MORNING AT 9:30

Kent Theater

(E. N. ADAMS presiding)

Symposium of the Division of Solid-State Physics

T1. Review of Lake Placid Conference on Dislocations and Mechanical Properties. J. C. FISHER, *General Electric.* (50 min.)

T2. Infrared Studies of Impurity Centers in Silicon. G. PICUS, *Naval Research Laboratory.* (25 min.)

T3. Exciton-Induced Photoconductivity in Alkali Halides. R. MAURER, *University of Illinois.* (25 min.)

T4. The Influence of Lattice Imperfections on Thermal Conduction in Solids at Low Temperatures. P. G. KLEMENS, *Commonwealth Scientific and Industrial Research Organization, Sydney.*

SATURDAY AFTERNOON AT 1:30

Kent Theater

(A. W. LAWSON presiding)

Symposium of the Division of Solid-State Physics (continued)

U1. Singularities in the Density of States. J. C. PHILLIPS, *Bell Telephone Laboratories.* (40 min.)

U2. Diffusion of C, O, and N in Ta, V, and Nb. R. W. POWERS, *General Electric Research Laboratory.* (25 min.)

U3. Magnetic Susceptibility of Some Weakly Magnetic Metals. R. BOWERS, *Westinghouse Research Laboratories* (25 min.)

U4. Low-Temperature Resistance Maximum in Dilute Alloys. R. W. SCHMITT, *General Electric Research Laboratory.* (25 min.)

SATURDAY AFTERNOON AT 1:30

Eckhart 133

(A. C. G. MITCHELL presiding)

Invited Papers in Beta-Ray Physics

V1. Double Beta Decay. L. M. LANGER, *Indiana University.* (30 min.)

V2. Beta-Gamma Directional Correlation. T. B. NOVEY, *Argonne National Laboratory.* (30 min.)

V3. Isomerism in Deformed Nuclei. C. H. HAMMER, *Iowa State College.* (30 min.)

SATURDAY AFTERNOON AT 1:30

Mandel Hall

(H. D. SMYTH presiding)

Invited Papers in Nuclear Physics

W1. The Proton Compton Effect. G. BERNARDINI, *University of Illinois.* (30 min.)

W2. The Argonne 12.5-Bev Accelerator. J. J. LIVINGOOD, *Argonne National Laboratory.* (30 min.)

W3. MURA Accelerator Developments. KEITH SYMON, *University of Wisconsin.* (30 min.)

SATURDAY AFTERNOON AT 1:30

Social Sciences 122

(L. A. TURNER presiding)

Neutron Physics

X1. New System for Fast Neturon Cross-Section Measurement.* L. CRANBERG, W. P. AIELLO, R. K. BEAUCHAMP, H. J. LANG, J. S. LEVIN, AND J. E. MIDGLEY, *Los Alamos Scientific Laboratory.*—By using pulsed-beam time-of-flight technique[1] and a thick proton recoil detector, high efficiency (45%) for detection of neutrons above 80-kev energy can be combined with discrimination against gamma rays and "wrong" energy neutrons. This makes possible neutron counting rates of the order of 100 per second at 1-Mev neutron energy using the $Li^7(p,n)Be^7$ reaction with a 1.5-kev thick Li target. To further expedite data taking, a sweep voltage of ± 25 kv is applied to the target at 10 cps, thereby modulating the energy of the accelerating particle. Signals from the neutron detector are converted to pulses whose heights are proportional to the instantaneous sweep voltage and are then presented on a 100-channel analyzer. Thus one obtains 100 data points corresponding to a 50-kev energy interval with a single energy setting of the acclerator. Results will be given for 1.5-kev resolution total neutron cross sections and a (p,n) excitation function.

* This work performed under the auspices of the U. S. Atomic Energy Commission.

[1] L. Cranberg and J. S. Levin, Phys. Rev. **103**, 343 (1956).

X2. Neutrons from the D-D and P-D Reactions.* A. H. ARMSTRONG, L. CRANBERG, AND R. L. HENKEL, *Los Alamos Scientific Laboratory.*—An investigation has been made of the neutron spectra resulting from D−D reactions for a range of incident deuteron energies of 4.75 to 7.33 Mev, using a pulsed-beam time-of-flight method. In addition to monoenergetic neutrons from the reaction $D(d,n)He^3$, a continuum of neutrons is observed corresponding to $D(d;n,p)D$. The yield of the latter reaction has been measured at about 0.5-Mev intervals at zero degrees, and at an energy of 6.3 Mev an angular distribution has been obtained for both reactions. At 6.3-Mev deuteron energy and at zero degrees the yield of the continuum for neutron energies above 0.95 Mev is 17% of the yield of monoenergetic neutrons. The yield from both reactions is strongly forward in the laboratory reference frame, and for the breakup process increases rapidly with increase in energy above threshold. Results for the zero degree neutron yield from the $D(p,n)P,P$ reaction for 7.0-Mev proton energy will also be given.

* This work performed under the auspices of the U. S. Atomic Energy Commission.

X3. Neutron Capture Gamma Rays from Gold.* BERNARD HAMERMESH, DAVID ROSE, AND ROBERT K. SMITHER, *Argonne National Laboratory.*—The spectrum of the gamma rays resulting from the capture of neutrons by Au^{197} nuclei is being studied using the Argonne 7.7-m bent crystal spectrometer.[1,2] The source is a gold foil $10\times2\times0.025$ cm located inside of a straight-through beam hole in the CP-5 reactor. The following gamma rays have been found (energy in kev) having the approximate intensities (in photons per 100 captured neutrons) indicated in the parentheses: 97.1 (2.2), 144.9 (0.2), 158.4 (3.4), 162.6 (0.3), 166.0 (0.5), 168.2 (4.9), 169.9 (1.9), 180.5 (0.6), 185.2 (0.3), 187.7 (0.8), 193.5 (4.8), 203.8 (1.0), 207.8 (0.9), 214.9 (12.8), 219.0 (0.6), 235.2 (5.1), 238.8 (1.7), 247.1 (7.7), 269.8 (8.9), 271.0 (1.5), 276.0 (1.4), 291.0 (2.1), 308.0 (1.1), 311.0 (1.1), 316.0 (1.5), 328.0 (3.0), 343.0 (2.2), 350.0 (2.1), 354.0 (0.9), 370.0 (1.3), 381.0 (5.1), 439.0 (1.8). The energies have been measured to 1 to 2 parts in 10^3 in this work. A preliminary study of the region from 439 kev to the upper energy limit of the spectrum, 6.5 Mev, has revealed very few lines. Additional work in this region and in the region below 90 kev is to be carried out.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

[1] B. Hamermesh, Bull. Am. Phys. Soc. Ser. II, 1, 220 (1956).

[2] D. Rose and B. Hamermesh, Bull. Am. Phys. Soc. Ser. II, 1, 189 (1956).

X4. The 2.07-Mev Resonance in the Neutron Total Cross Section of C^{12}. H. O. COHN, J. K. BAIR, AND H. B. WILLARD, *Oak Ridge National Laboratory.*—The 2.07-Mev resonance in the $C^{12}+n$ reaction was reinvestigated. The total cross section was measured by a conventional transmission experiment by use of a high-purity graphite sample. The detector was a propane recoil counter. Neutrons were produced by the $Li^7(p,n)Be^7$ reaction from a thin metallic layer of the metal evaporated in place. The following factors contributing to changes in the measured cross-section values were carefully examined: (1) Pure elastic scattering may not be the only mode of interaction. (2) Background neutrons. (3) In-scattering correction. (4) Alignment of source, sample, and counter. (5) Energy resolution. (6) Presence of a low-energy group of neutrons in the $Li^7(p,n)$ reaction. Applying the above corrections one obtains the value of 5.7 ± 0.2 barns for the peak cross section, in good agreement with the theoretical value of 6.01 barns for a $J=5/2$ resonance. It is felt that the earlier work[1] did not consider the above corrections in enough detail. Angular distributions showed that this level is due to d-wave neutrons.[1] It is concluded from the present data that the resonance occurs at 2.076 ± 0.008 Mev with a natural width of 8 kev and is a $D_{5/2}$ level.

[1] J. E. Wills, Jr., Bull. Am. Phys. Soc. Ser. II, 175 (1956).

X5. Differential Cross Section for Neutrons Scattered from the 585-kev Resonance in S^{32}.† R. O. LANE AND J. E. MONAHAN, *Argonne National Laboratory.*—The angular distribution of neutrons scattered in the vicinity of the 585-kev resonance in S^{32} has been measured with apparatus previously described.[1] Since this resonance is used as a standard in the determination of the resolution, Δ, of an incident neutron beam it is desirable to obtain an accurate measure of the associated parameters. The data indicate that $J\geq 5/2$, $l\geq 2$, with a measured half-width of 3.8 kev. For a rectangular spectrum, Δ, and assuming $J=5/2$, $l=2$, a good fit to the data is obtained with $\Gamma=1$ kev and $\Delta=3.7$ kev. From total cross-section measurements on this resonance Peterson, Barschall, and Bockelman[2] concluded that $J=3/2$, $l=1$ or 2, and $\Gamma=1.5$ kev. The analysis for $l=\geq 3$ requires observations at more angles. While no multiple scattering corrections have been made, these are not expected to change the basic conclusions.

† Work performed under the auspices of the U. S. Atomic Energy Commission.

[1] A. Langsdorf, Jr., and R. O. Lane, Phys. Rev. **98**, 1147 (1955); Langsdorf, Lane, and Monahan, Argonne National Laboratory Report ANL-5567 (1956).

[2] Peterson, Barschall, and Bockelman, Phys. Rev. **79**, 593 (1950).

X6. Total Neutron Cross Sections in the kev Region: Cr and Fe.† CARL T. HIBDON, *Argonne National Laboratory.*—Transmission cross sections of Cr and Fe as a function of neutron energy have been measured from one to 410 kev. Resonances

located at 51, 97.5, 120.4, 138, 142, 146, 152, 243, 325, 366, and 406 kev are attributable to Cr^{52} and appear to be due to *s*-wave neutron interaction. About 25 smaller resonances are attributable to less abundant isotopes of Cr. Six resonances in the region from 3 to 9.5 kev were identified as Cr^{53} resonances. The data for iron are also complicated, there being resonances at 29.17, 75.6, 85.5, 127.7, 138, 145, 162, 188, 219, 272, 316, 360, 388, and 406 kev attributable to Fe^{56}. All appear to be due to *s*-wave neutron interaction. A resonance near 7.5 kev and several others are due to Fe^{54}. Numerous small peaks indicate the presence of resonances of Fe^{57}. These results agree in general with the data of Gibbons,[1] who made measurements up to 120 kev. The experimental peak cross sections, however, are greater than his, presumably because of better resolution. Values of $\overline{\Gamma}_n^0/\overline{D}$ found for Cr^{52} and Fe^{56} in the region covered are small as compared to the value for Cr^{53} in the 3- to 10-kev region.

† Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] J. H. Gibbons, Phys. Rev. **102**, 1574 (1956).

X7. Neutron Cross-Section Measurements on Niobium.† A. SAPLAKOGLU, L. M. BOLLINGER, AND R. E. COTÉ, *Argonne National Laboratory.*—The possibly anomalous behavior of the neutron cross section for niobium, as suggested by the extremely small transmission dips produced by its resonances, indicated the desirability of a more complete study than those previously performed. Therefore the total cross sections of niobium have been studied from 30 ev up to 10 000 ev with the new Argonne fast chopper. Transmission measurements with 4 different sample thicknesses were obtained with a higher resolution, about 0.04 μsec/meter, than previously used. Transmission dips were observed at 35.9, 42.2, 94.3, 106, 119, 194, 244, 336, 381, 463, 500, 746, 947, 1018, and 1184 ev, and many others at higher energy. To some extent the small size of the observed transmission dips is caused by the chance occurrence of atypically small resonances at low energies. The average resonance is, however, unusually narrow and the $\overline{\Gamma}_n^0/\overline{D}$ value obtained, about 10^{-5}, is the smallest value yet reported; this value is in good agreement with that predicted by the optical model with a simple square well potential. In other respects the cross-section behavior is not unlike that of neighboring nuclei.

† Work performed under the auspices of the U. S. Atomic Energy Commission.

X8. Age to Indium Resonance for D-D Neutrons in Water.* V. SPIEGEL, JR., D. O. OLIVER,† AND R. S. CASWELL, *National Bureau of Standards.*—The 1.44-ev indium resonance age has been determined from activation measurements for a $D(d,n)He^3$ neutron source in water at 0°, 8.5°, 20.3°, 41.5°, 90°, 138.5°, and 159.7° with respect to the incident 250-kev D^+ beam. For this source the neutron energy varies from 3.12 Mev at 0° to 2.00 Mev at 180°. The ages determined at these angles were 44.5 ± 1.8 cm², 44.5 ± 1.8 cm², 44.2 ± 1.8 cm², 40.5 ± 2.4 cm², 33.4 ± 1.3 cm², 34.2 ± 2.1 cm², and 37.9 ± 2.4 cm². The ages in the backward hemisphere are high, due to the ducting effect of the pipe through which the deuteron beam enters the water medium. Averaging the flux over angle by the Gauss integration procedure at 20.3°, 90°, and 159.7° gave a mean neutron age to indium resonance of 36.3 cm². If the 159.7° age is lowered by 30% to correct for the ducting effect, then the mean age is lowered by 5% to 34.5 cm². The total error in this value is estimated to be ±5%. Comparison with theoretical calculations of neutron age will be discussed.

* Supported by the U. S. Atomic Energy Commission.
† Now at the Massachusetts Institute of Technology.

X9. Radiation Widths in the Slow Neutron Resonances of Eu.† H. H. LANDON, *Brookhaven National Laboratory.*—The study of the radiation widths in the slow neutron resonances of Eu has been continued using the B.N.L. crystal spectrometer to measure total neutron cross sections in the region of a few electron volts. The close spacing of levels in Eu permits the analysis of level parameters to the precision required for radiation width distribution studies. Previous measurements[1] have indicated the possibility that radiation widths fall into two distinct groups in Eu^{151}. New measurements give the parameters for a previously unresolved level in Eu^{151} at $E_0=3.72$ ev.[2] The radiation width Γ_γ for this level is 69 ± 7 mv. This result places this level in the group of levels having measurably lower width than the two most accurately known levels in Eu^{151}. The radiation widths of two levels in Eu^{153} at $E_0=2.455$ ev and 3.94 ev[2] are found to be 89 ± 2 mv and 91 ± 5 mv, respectively. The total cross-section measurements also yield a value of σ_P, the potential scattering, a parameter which can be related to the nuclear radius.

† Work performed under contract with U. S. Atomic Energy Commission.
[1] H. H. Landon and V. L. Sailor, Phys. Rev. **98**, 1267 (1955).
[2] The isotopic assignment has been made by J. A. Harvey, Bull. Am. Phys. Soc. Ser. II, **1**, 347 (1956), this issue, and private communication.

X10. Neutron Resonance Parameters of Eu^{151} and Eu^{153}. J. A. HARVEY AND R. C. BLOCK, *Oak Ridge National Laboratory.*—The total neutron cross sections of samples of Eu^{151} (enriched to 91.9%) and Eu^{153} (enriched to 95.0%) have been measured with the Oak Ridge National Laboratory fast chopper. The transmission curves have been analyzed from 1 to 10 ev to obtain the parameters of the resonances. Several of the resonances[1] which have been reported previously are shown to be two resonances with a resonance in each isotope. In this energy range 11 resonances were observed in Eu^{151} and 8 resonances in Eu^{153}. The average level spacing per spin state is 2.4 ± 0.7 ev in Eu^{153} and 1.2 ± 0.2 ev in Eu^{151} (including the three Eu^{151} resonances[1] below 1 ev). From the resonance parameters up to 10 ev, the strength function (the ratio, $\overline{\Gamma}_n^0/D$) of Eu^{151} is computed to be more than twice that of Eu^{153}.

[1] D. J. Hughes and J. A. Harvey, "Neutron cross sections," Brookhaven National Laboratory Report BNL-325 (1955).

X11. Gamma Radiation from Resonance Neutron Capture in Hg. E. R. RAE, *Atomic Energy Research Establishment, Harwell, England,* AND H. H. LANDON,* *Brookhaven National Laboratory.*—An investigation has been undertaken to study the possibilities of observing individual high energy capture gamma rays associated with resonance neutron capture. The gamma rays are detected by large NaI scintillation detectors placed near a target irradiated by neutrons from the A.E.R.E. linear electron accelerator. The pulses from the gamma-ray detectors are time analyzed to yield captured neutron energy, and pulse-height analyzed to yield gamma-ray energy. Hg was chosen as the first target to study because of its relatively close level spacing near the binding energy of the neutron, and because the capture gamma-ray spectrum, as recently measured by Adyasevich *et al.*, shows certain simple features. Gamma-ray transitions associated with capture in the negative energy level of Hg^{199}, which dominates the thermal capture in Hg, are not observed directly to the ground state. On this basis the spin of this level is assigned 0^-. If capture should occur, however, in the other possible state, a 1^- state, E-1 transitions of 8 Mev should be observed to the 0^+ ground state of Hg^{200}. Such gamma rays have been looked for in the 34-ev resonance in Hg^{199}, as well as in two higher energy resonances assigned to this isotope. Evidence for the existence of such gamma rays will be presented.

* Work performed while on leave-of-absence to Atomic Energy Research Establishment, Harwell, England.

X12. Ratio of Neutron Widths to Level Spacings in Heavy Nuclides.* R. B. SCHWARTZ, V. E. PILCHER,† D. J. HUGHES, AND R. L. ZIMMERMAN, *Brookhaven National Laboratory.*—

The ratio of the average reduced neutron width to the level spacing, Γ_n^0/D, has been measured for a number of isotopes by measuring the widths and spacings of individual levels, as well as by measuring the average total cross section in the kilovolt region.[1] The results have been compared with recent predictions[2] of the "cloudy crystal ball" model, as calculated using a rounded-edge potential well, for several different well depths. Our results show a peak in the Γ_n^0/D distribution at mass $A=155$, which is consistent with a 42-Mev potential well. The experimental peak, however, is lower in amplitude than that predicted by the theory. Further, our values of Γ_n^0/D in the region around $A=235$ are considerably higher than those in the region of $A=115$, whereas all of the calculations so far indicate that these "wings" of the Γ_n^0/D peak should be approximately symmetric.

* Work carried out under contract with the U. S. Atomic Energy Commission.

† Now at Union College, Schenectady, New York.

[1] D. J. Hughes and V. E. Pilcher, Phys. Rev. **100**, 1249(A) (1955).

[2] V. F. Weisskopf, *Amsterdam Conference on Nuclear Reactions* (June, 1956).

SATURDAY AFTERNOON AT 2:00

Cobb 110

(LOTHAR MEYER presiding)

Low-Temperature Physics; Solid-State Physics

Y1. Nucleation and Growth in a Photosensitive Gold Glass. R. D. MAURER, *Corning Glass Works.*—The kinetics of gold colloid formation in a photosensitive glass have been observed with light scattering and optical absorption. The optical absorption is proportional to the number of particles times their volume while the scattered light is proportional to the number of particles times the square of their volume. Absorption and scattering together offer the possibility of determining both number and volume or, when these change with time, the nucleation frequency and growth. Assuming homogeneous nucleation and that the volume of a nucleated particle increases proportional to the time raised to a power m, the initial change of scattering and absorption with time are determined by m. A value of $m=\frac{1}{3}$ fits the data. The small depolarization of the scattered light is not inconsistent with the view that the particles are almost spherical. Assuming that the particles are spherical and possess the optical characteristics of bulk gold, the Mie theory yields expressions for the nucleation frequency and growth of a nucleated particle. These assumptions give nucleation frequencies of the order of 10^7 cm^{-3} sec^{-1} with the largest particles a few hundred angstroms in diameter.

Y2. Diffusion and Solubility of Interstitial Zn in ZnO. D. G. THOMAS, *Bell Telephone Laboratories* (introduced by A. R. Hutson).—Interstitial Zn may readily be introduced into single crystals of ZnO either by dipping the crystals into molten Zn or into Zn vapor mixed with an inert gas. The Zn behaves as a donor with a low ionization energy and is observed through conductivity changes. The solubility in atoms/cc from saturated Zn vapor is $n=3.4\times10^{20}\exp(-0.65e/kT)$. The diffusion coefficient between 200 and 370°C obeys $D=3\times10^{-4}\exp(-0.55e/kT)$ cm^2/sec. These results are in agreement with previously published data on the oxidation of Zn,[1] showing that oxidation occurs by the diffusion of interstitial Zn through a crystalline layer of oxide. The similarity of the diffusion characteristics to those of other interstitial species in various semiconductors shows that the donor is interstitial Zn and not on oxygen vacancy. The rapid diffusion even at temperatures where the solubility is low means that rapid quenching is necessary in order to dope the crystals. It is likely that the high-temperature diffusion of radioactive Zn into ZnO does not involve interstitial Zn.

[1] Moore and Lee, Trans. Faraday Soc. **47**, 501 (1951).

Y3. Dislocation Movements and Glide Band Formation in LiF. W. G. JOHNSTON AND J. J. GILMAN, *General Electric Research Laboratory.*—Etching techniques are described for revealing dislocations in LiF. The high sensitivity of these techniques enables one to observe the glide of individual dislocations. A technique for introducing isolated dislocations into crystals is described. This technique allows observations to be made of single dislocations as they are moved by applied stress in a controllable and reversible manner. By means of continuous etching the creep of single dislocations is clearly recorded. The multiplication of single dislocations to form glide bands consisting of thousands of dislocations has been observed. The multiplication process has been investigated by alternate etching and chemical polishing to determine the three-dimensional dislocation structure. The glide-band formation, as inferred from etch pit studies, is described.

Y4. Creep Deformation of Floating Ice Shelves. J. WEERTMAN, *U. S. Naval Research Laboratory.*—The Norwegian-British-Swedish Antarctic expedition investigated the creep deformation of the ice shelf on which they were stationed.[1] They found that a two-kilometer base line stretched at a rate of 30 cm/month (a creep rate of 1.8×10^{-2}/year). In order to compare this creep rate with the results of the laboratory experiments on the creep of ice which have been carried out by Glen[2] it is necessary to know the stress distribution in a floating ice shelf. This stress distribution has been found by solving, for this particular problem, the general creep relations given by Nye.[3] One obtains for the rate of extension of a floating ice shelf the expression $(\rho_I g h^2/4)^n(1-\rho_I/\rho_W)^n/(\int_0^h A\,dx)^n$ where h is the thickness of the shelf, g is the gravitational acceleration, ρ_I is the average density of the ice, ρ_W is the density of the sea water, x is measured vertically from the bottom of the shelf, n is a constant ($\sim$4.2), and A is a stress independent-temperature dependent term which can be evaluated[3] from the experimental results of Glen. The rate of extension given above is constant from the top to the bottom of the shelf. The creep rate calculated from the foregoing expression using the experimental results of Glen is in good agreement with that observed by the Norwegian-British-Swedish expedition.

[1] V. Schytt, J. Glaciology **2**, 204 (1953).

[2] J. W. Glen, Proc. Roy. Soc. (London) **A228**, 519 (1955).

[3] J. F. Nye, Proc. Roy. Soc. (London) **A219**, 477 (1953).

Y5. Structure of the Intermediate State in Superconducting Lead. P. B. ALERS, *U. S. Naval Research Laboratory.*—A new method of observing the structure of the intermediate state in superconductors has been developed. In common with previous methods,[1,2] this technique depends on the fact that the applied magnetic field penetrates the normal areas and is excluded from superconducting areas. The field distribution is rendered visible by observing the Faraday effect in a paramagnetic compound (cerous nitrate in glycerol) placed on the

surface of the superconductor. The results on two polycrystalline lead disks will be reported. One was a lead alloy containing about 3% antimony; the other was relatively pure (99.95% Pb). The pure lead exhibited conventional behavior and the intermediate state showed no resolvable fine structure. Hysteresis effects were small. The lead alloy, on the other hand, exhibited many of the characteristics of the hard superconductors, having a much higher critical field than pure lead and showing strong frozen-in moments. Very complicated field distributions could be generated in the alloy. Photographs were taken of both the pure lead and the alloy for various fields.

[1] A. G. Meshkovsky and A. I. Shalnikov, J. Phys. U.S.S.R. **11**, 1 (1947).
[2] A. L. Schawlow, Phys. Rev. **101**, 573 (1956).

Y6. Isotopic Dependence of the Temperature of the Transition I→II in Methane. M. J. FREISER* AND H. M. JAMES, *Purdue University*.—CH_4 shows an orientational transition at 20.4°K. A similar transition occurs in CD_4 at 27.1°K. A classical treatment of the transition CD_4 has been given previously by Keenan and James.[1] To account for the isotopic shift of the transition temperature the problem has been treated quantum mechanically. The effects of the different spacings of the rotational levels of CH_4 and CD_4 molecules, and the different distributions of these molecules among the symmetry species, *meta*-, *para*-, and *ortho*-methane, have thus been taken into consideration. The calculation is based on the model developed by Keenan and James and is carried out in the internal field approximation. The treatment shows that, at a temperature T_c, the system can undergo a transition from a disordered to an ordered state as the temperature decreases. A relation has been obtained between T_c for CH_4 and T_c for CD_4 which depends on the strength of the molecular coupling. When this parameter is fixed so as to yield the observed transition temperature for CH_4, one obtains for CD_4 a transition temperature of 33.8°K. The predicted shift, though larger than that observed, is in the right direction.

* Now at Midwestern Universities Research Association, Madison, Wisconsin.
[1] T. A. Keenan and H. M. James, Phys. Rev. **99**, 1660(A) (1955).

Y7. Calorimetric Measurements of the Heat of Vaporization of Liquid He^3.* BERNARD M. ABRAHAM, DARRELL W. OSBORNE, AND BERNARD WEINSTOCK, *Argonne National Laboratory*.—Although the heat capacity of liquid He^3 has been measured down to 0.23°K, it is not possible to make a reliable extrapolation from this temperature to absolute zero to obtain the entropy. However, the entropy of the liquid can be determined at a given temperature from the entropy of the gas, which is known from the Sackur-Tetrode equation, and the heat of vaporization at that temperature. The heat capacity data can be combined with this to obtain the entropy at other temperatures. Heretofore the only values of the heat of vaporization that have been available were derived from vapor pressure measurements and were subject to as much as 2% error because of uncertainties in the temperature scale and second virial coefficient. We have made calorimetric measurements of the heat of vaporization in the temperature range 1.2 to 2.1°K in order to provide more accurate values of the entropy. Although the quantity vaporized was at most 0.009 moles, the estimated probable error in the heat of vaporization is only 0.2%. The measured heat of vaporization will be compared with that calculated from vapor pressure data, and the values of the entropy of liquid He^3 from 0.23° to 2°K will be presented.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

Y8. Volume Flow Rate of the Helium II Film from 36-cm Glass Beakers.* J. H. WERNTZ, JR.† AND J. R. DILLINGER, *University of Wisconsin*.—The rate at which liquid helium flows out of glass beakers by means of the He II film has been studied at about 1.4°K. The normalized volume flow rate, R, has been measured as a function of H and H_0 up to values of 36 cm. H is the distance from the top of the beaker to the liquid inside and H_0 from the top to the liquid outside. For H less than one centimeter the usual large rates were obtained. For H slightly less than H_0, R falls rapidly but not abruptly to zero. Excluding these regions, R decreases for increasing H, and R increases for increasing H_0, contradicting predictions that R is independent of film length. The data closely follow a law, $R = (\text{constant}) \exp(-\text{constant}) \cdot H$, contradicting theories suggesting a power law dependence of R on H. A structure, sometimes of a nearly discontinuous nature, was observed in some curves. This structure was not reproducible but occurred under conditions not differing from those under which smooth curves were obtained. It may confirm a proposal made to account for results of an earlier experiment.[1]

* This work was supported in part by the Wisconsin Alumni Research Foundation and in part by the U. S. Atomic Energy Commission.
† Now at the University of Minnesota.
[1] W. C. Knudsen and J. R. Dillinger, Phys. Rev. **95**, 279 (1954).

SATURDAY AFTERNOON AT 2:00

Oriental 272

(W. D. WALKER presiding)

Mesons; Electron Pairs

Z1. Heavy Particle Production by 1.4 Bev π^- Mesons in a Propane Bubble Chamber.* N. P. SAMIOS AND J. STEINBERGER, *Columbia University*, M. SCHWARTZ, *Brookhaven National Laboratory*, M. CHRETIEN, *Brandeis University*, AND J. LEITNER, *Duke University*.—This is a continuation of a study of the properties of heavy unstable particles previously reported.[1] From a total of ~25 000 pictures, approximately 95 hydrogen events involving strange particle production have been identified. Of these, ~32 are of the sort $\pi^- + p \rightarrow \Sigma^- + K^+$ and ~63 of the sort $\pi^- + p \rightarrow \Lambda^0 + \theta^0$ or $\pi^- + p \rightarrow \Sigma^0 + \theta^0$. One event, previously unreported, is of the sort $\pi^- + p \rightarrow \Sigma^- + \tau^+$. Additional evidence for the angular distributions of production, the angular correlations of decay, and the existence of alternate decay modes will be presented.

* Supported by a joint program of the U. S. Atomic Energy Commission and Office of Naval Research.
[1] Budde, Chretien, Leitner, Samios, and Steinberger, Phys. Rev. **103**, 1827 (1956).

Z2. Elastic Scattering of 1.4 Bev π^- Mesons on Hydrogen in Propane Bubble Chamber.* J. STEINBERGER AND N. P. SAMIOS, *Columbia University*, M. SCHWARTZ, *Brookhaven National Laboratory*, M. CHRETIEN, *Brandeis University*, AND J. LEITNER, *Duke University*.—Approximately 1500 pictures taken with a propane bubble chamber at the Brookhaven

Cosmotron were systematically scanned for the reaction $\pi^-+p\rightarrow\pi^-+p$. A fiducial region inside the chamber was chosen in order to avoid difficulties with detection and identification near the walls. Identification criteria were coplanarity, angular correlation, ionization, and, where available, range. Eight-hundred fifty events were identified corresponding to a total pion track length of 178 290 g/cm² of hydrogen. After correcting for events which were missed due to small scattering angle ($<8°$) or large dip angle, the total cross section is found to be 11 ± 1 mb. The angular distribution shows a large forward diffraction peak, corresponding to a black sphere radius of 1.1×10^{-13} cm. In addition there is a considerable amount of backward scattering, 21% of the events having a scattering angle greater than 90° in the center of mass.

* Supported by a joint program of the U. S. Atomic Energy Commission and Office of Naval Research.

Z3. Photon Scattering and π^0 Production in Hydrogen. T. YAMAGATA, L. B. AUERBACH, G. BERNARDINI, I. FILOSOFO, A. O. HANSON, AND A. C. ODIAN, *University of Illinois.*—Protons, recoiling from scattered photons and from π^0 mesons, were analyzed by a magnet and detected by thin and thick scintillation counters. The scattered photons were observed by a Čerenkov counter whose pulses, together with the two proton pulses, were displayed on an oscilloscope. These were photographed and analyzed with respect to the proper time delays and pulse-height distributions in each of the counters. The observed CMS cross sections for Compton scattering (in units of 10^{-32} cm²/sterad) at 90°CMS were 1.81 ± 0.22, 3.22 ± 0.69, 6.08 ± 0.72, 12.8 ± 1.3, and 13.7 ± 1.6, respectively, at 193, 213, 239, 263, and 278 Mev; at 130° 3.56 ± 0.83, and 12.2 ± 1.2 at 198 and 239 Mev; and at 70° 6.85 ± 0.70 at 226 Mev. The experimental values around 200 Mev lie below that expected from the Thomson plus the magnetic dipole resonance amplitudes and may indicate an interfering electric dipole amplitude in this energy region. The observed π^0 CMS cross sections at 80° (in units of 10^{-30} cm²/sterad) were 6.5 ± 0.5, 9.0 ± 1.6, 10.0 ± 0.5, 12.1 ± 0.5, and 17.3 ± 0.8 at laboratory photon energies of 230, 235, 242, 256, and 272 Mev, respectively, in good agreement with those adopted by Watson *et al.*[1] for the 90° cross sections.

[1] Watson, Keck, Tollestrup, and Walker, Phys. Rev. **101**, 1159 (1956).

Z4. Cross Sections of 970 Mev π^- in Various Elements.* A. ABASHIAN, R. COOL, AND J. CRONIN, *Brookhaven National Laboratory.*—The attenuation of 970 Mev negative pions in a few selected elements has been measured. Using a well-collimated beam from the Cosmotron, data were obtained in each case as a function of the angle subtended by the final anticoincidence counter. Subsidiary measurements using thin Pb scatterers verify that none of the data used for the analysis requires correction for multiple Coulomb scattering. A correction for secondaries of interactions which cross the final counter has been applied, assuming that they are proportional to the solid angle over the small range of angles under consideration. Preliminary results for the total absorption cross sections in millibarns are: Be, 192 ± 6; C, 229 ± 8; Al, 462 ± 38; Ca, 570 ± 39; Cu, 846 ± 72; Sn, 1186 ± 68; Pb, 1828 ± 100. For the light elements Be and C, the diffraction cross sections have also been obtained under the assumption that the angular dependence is correctly given by theory.[1] They are (in millibarns): Be, 75 ± 10; C, 109 ± 14. Interpretation of the results in terms of nuclear radii and a comparison with the work of Sternheimer[2] will be discussed.

* Work carried out under the auspices of the U. S. Atomic Energy Commission.
[1] Fernbach, Serber, and Taylor, Phys. Rev. **75**, 1352 (1949).
[2] R. M. Sternheimer, Phys. Rev. **101**, 384 (1956).

Z5. Interaction of 38 Mev π^- Mesons in Deuterium.† A. M. SACHS, H. WINICK, AND B. A. WOOTEN, *Columbia University.*—Using an external magnetic channel to obtain a low-energy beam from the Nevis Cyclotron, measurements have been made of scattering and absorption in liquid deuterium of 38 ± 3 Mev positive pions.[1] Since protons from the absorption process and scattered pions cannot be distinguished by range alone, the mass and energy of the emerging particles are determined by analyzing scintillation counter pulse heights. For pions scattered with energy greater than 16 Mev the differential cross section at 45, 60, 90, 113, 135, and 150 degrees in the laboratory system are 0.31 ± 0.12, 0.53 ± 0.09 0.64 ± 0.08, 0.84 ± 0.09, 0.71 ± 0.09, and 1.10 ± 0.12 mb/sterad, respectively. Protons from the absorption process fit the distribution $(0.18\pm0.02)+(0.80\pm0.05)\cos^2\theta$ mb/sterad in the center-of-mass system. Because of the energy spread of the incident beam, the variation of energy loss in the deuterium, and the relatively high (16 Mev) detection threshold energy, a clear separation between elastic and inelastic pion scatterings cannot be obtained. Preliminary results at 58 Mev, where the threshold is considerably below the elastic energy, indicate that at least 80% of the scattering is elastic.

† This work was performed under the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] D. Bodansky and A. Sachs, Phys. Rev. **98**, 240 (1955).

Z6. Electron Pair Production by 400- to 800-Mev Electrons in Nuclear Emulsions.* F. J. LOEFFLER, *Cornell University.*—The mean free path for the direct electron pair production by high-energy electrons in Ilford G-5 emulsions has been measured. Glass mounted emulsions 400 μ thick were exposed at the end of a magnetic analyzer to electrons of energies between 400 and 800 Mev produced in a 68-mil lead target by a bremsstrahlung beam from the Cornell strong-focusing electron synchrotron. Because of the resolution of the analyzer, the energies of electrons entering the edge of an emulsion at various points are known. Electron tracks have been followed in the emulsions from the entering edge to a depth of 1 cm, and to date 29 tridents (electron pairs starting within 0.5 μ of the primary) have been analyzed corresponding to 1472 cm of track. This gives a value for the mean free path for the process at 531 ± 110 Mev of 50.8 ± 9.4 cm. Correction for the pseudo-trident background will be made utilizing the bremsstrahlung pair distribution found in these emulsions, and it is presumed that this will bring the measured mean free path closer to the theoretical value. Measurements at other energy points will also be made.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

Z7. Positronium Formation in Polymers.* S. BERKO AND B. C. GROSECLOSE, *University of Virginia.*—The complex annihilation lifetime of positrons in some solids and liquids can be explained on the basis of positronium formation.[1] As part of a program to study the parameters influencing positronium formation, we have measured lifetimes as a function of crystallinity in teflon. The long-lived τ_2 component showed the same order-disorder effect as observed during the melting of a crystal[2]; τ_2 ranged from 3.5×10^{-9} sec at 63% crystallinity to 2.6×10^{-9} sec at 87% crystallinity for Teflon of 5×10^5 molecular weight. Higher molecular weight samples ($3\text{–}7\times10^6$) showed large lifetimes and smaller changes with crystallinity. To study the dependence on molecular weight, lifetimes were measured in silicone fluids (dc 200) of various viscosity. τ_2 ranged from 3.25×10^{-9} sec (55%) for 10^6 centistokes to 2.7×10^{-9} sec (49%) for 1 centistoke viscosity. The percentage of positrons annihilating via τ_2 (quoted in parentheses above), is surprisingly high, indicating a large electron capture cross section into positronium states.

* Supported by the Office of Naval Research.
[1] For review articles see S. Berko and F. L. Hereford, Revs. Modern Phys. **28**, 299 (1956); R. A. Ferrell, Revs. Modern Phys. **28**, 308 (1956).
[2] Landes, Berko, and Zuchelli, Phys. Rev. **103**, 828 (1956).

Z8. Annihilation of Positrons in Liquid Helium. J. D. WACKERLE AND R. STUMP, *University of Kansas.*—The annihilation lifetime of positrons in liquid helium has been reported to have two components: one very short, $\tau \sim 2\times10^{-10}$ sec, one with $\tau = 2.7\times10^{-9}$ sec.[1] Present work indicates that, in liquid helium, some of the positrons are annihilated with a much longer mean life. It is proposed that the annihilation of positrons in liquid helium is due to the formation of positronium by about one third of all positrons. The positronium decay leads to the very short and very long lifetime components. The intermediate lifetime is then due to the annihilation of free positrons and is longer than found in most condensed materials due to the low electron density in liquid helium. Experiments on the three quantum annihilation rate and the relative intensity of the three components are in agreement with this explanation.

[1] Graham, Paul, and Henshaw, Bull. Am. Phys. Soc. Ser. II, 1, 68 (1956).

Z9. Positron Lifetimes in Metals.* T. A. POND, *Washington University.*—Comparisons of positron annihilation lifetimes in several metals have been undertaken, as suggested by Ferrell's recent calculations.[1] Relative measurements on magnesium and aluminum show that the former's mean life is longer by $(4.5\pm1.5)\times10^{-11}$ sec. A preliminary experiment shows that the mean life in cesium exceeds that in aluminum by $(1.4\pm0.5)\times10^{-10}$ sec. No change in the cesium lifetime outside the error is observed when the sample is solidified. The agreement with Ferrell's work seems satisfactory. Absolute measurements are in progress.

* Supported by the Office of Naval Research.
[1] R. A. Ferrell, Revs. Modern Phys. (to be published).

SUPPLEMENTARY PROGRAMME

SP1. Arc Initiated Discharge in Magnetic Field in High Vacuum. II. Magnetoionic Expander Type of Discharge.* J. SLEPIAN, *Westinghouse Research Laboratories.*—This second type of discharge is again unaffected by space-charge limitation. The magnetoionic expander receives the intense mixture of ions and electrons in equal numbers at its short input end. The ions and electrons which are initially accelerated and later retarded by the reaction of the magnetic field upon the nonterminating currents induced in the moving gas, precipitate out upon insulated slats bridging the long output end of length L of expander. There is negligible energy input into the expander. The initial kinetic energy of the ions is mostly random at the start and becomes ordered when, greatly lengthened, the ions and electrons precipitate upon the terminating slats. The isotopes of the ions become separated, the degree of their separation varying as L^2. These results are confirmed by a mathematical treatment of the passage of ions and electrons up the expander, the basic equation being $n_i m_i \mathbf{v}_i \cdot \nabla \mathbf{v}_i = n_i e\mathbf{E} + n_i e/c[\mathbf{v}_i \times \mathbf{H}] - \text{grad} n_i kT + \mathbf{P}_{i,jk}$.

* To be called for at the end of Session Q if the Chairman rules that time permits.

SP2. Compressional Creep of Tin Single Crystals.* J. WEERTMAN, *U. S. Naval Research Laboratory.*—Compressional creep tests were run on tin single crystals oriented so that the direction of compression was along the c direction. The apparatus used was similar to one described by Christy.[1] The dimensions of the specimens were approximately $0.33\times0.33\times1.2$ cm. The direction of compression was along one of the short dimensions of the specimen. The temperature range covered was from room temperature to temperatures close to the melting point of tin. Tests were run at stresses of either 6.3×10^7 dynes/cm^2 or 2.5×10^7 dynes/cm^2. Two activation energies of creep were found: approximately 24 500 cal/mole above 120°C and 12 000 cal/mole below this temperature. These results are quite similar to those found for tensile creep experiments on tin single crystals.[2] In the explanation of the results given in reference 2 it was necessary to assume that the climbing dislocation did not lie parallel to the c direction. The present experiment removes the necessity of making this assumption since the slip planes containing the c axis are the least likely to take part in the deformation.

* To be called for at the end of Session L if the Chairman rules that time permits.
[1] R. W. Christy, Acta Metallurgica **2**, 284 (1954).
[2] J. Weertman and J. E. Breen, J. Appl. Phys. **27**, 1189 (1956).

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Brown, William Fuller, Jr.—D6
Brussel, Morton K. and John H. Williams—P2
Buschert, R., I. G. Geib, and K. Lark-Horovitz—Q2
Butler, J. W., K. L. Dunning, and R. O. Bondelid—G7
Cameron, J. R.—E3
Chen, S. W. and N. M. Hintz—G8
Cheston, W. B., A. E. Glassgold, M. L. Syrin, S. Schuldt, and G. W. Erickson—P6
Childs, William J. and Leonard S. Goodman—R1
Chinowsky, William—M2
Church, E. L. and J. Weneser—J12
Clayton, Lorimer, Quitman Williams, and T. L. Weatherly—Q3
Cohn, H. O., J. K. Bair, and H. B. Willard—X4
Connors, D. R. and W. C. Miller—P12
Coté, R. E. and L. M. Bollinger—G13
Cranberg, L., W. P. Aiello, R. K. Beauchamp, H. J. Lang, J. S. Levin, and J. E. Midgley—X1
Cronin, J. W., A. Abashian, and R. L. Cool—R6
Danos, M.—R10
deMars, G. A., H. Statz, L. Davis, Jr., and A. Adams, Jr.—C9
Denney, J. M.—L13
Denny, J. H. and D. H. Tomboulian—L10
DeSorbo, W. and D. Turnbull—L8
Dolan, P. J., H. A. Fincher, P. J. Kenny, S. Berko, and W. D. Whitehead—P9
Duga, J. J., A. C. Beer, and R. K. Willardson—K11
Dunning, K. L., J. W. Butler, and R. O. Bondelid—J1
Ehrenreich, H.—K9
Ewan, G. T., J. W. Knowles, and D. R. Mackenzie—J8
Fireman, E. L.—R4
Fisher, J. C.—T1
Fiske, M. D., R. M. Walker, J. W. Corbett, and J. M. Denny—L11
Ford, W K., Jr., A. L. Stamper, and J. W. Beams—L1
Freiser, M. J. and H. M. James—Y6
Fritts, R. W. and S. Karrer—K12
Fukuda, Nobuyuki and Julius Kovacs—N7
Gifford, F. and E. Coomes—L3
Glasser, R. G. and N. Seeman—B7
Glassgold, A. E., W. B. Cheston, M. L. Stein, S. Schuldt, and G. W. Erickson—P5
Goldsmith, George J.—D1
Green, M. S. and R. E. Nettleton—N13
Grodzins, L.—J7
Hamermesh, Bernard, David Rose, and Robert K. Smither—X3
Halsted, R. E.—C2
Hammer, C. H.—V3
Harvey, J. A. and R. C. Block—X10
Hatch, Albert J. and H. Bartel Williams—Q11
Havas, Peter—N12
Hereford, F. L., B. M. McCormac, M. F. Steuer, and C. D. Bond—P7
Herring, D. F., Ren Chiba, B. R. Gasten, and H. T. Richards—G1
Hibdon, Carl T.—X6
Hill, D. E.—C7
Hoang, T. F., M. F. Kaplon, and G. Yekutieli—B8
Holland, Robert E. and Ralph C. Ehlert—G5
Holmgren, H. D., E. H. Geer, R. L. Johnston, and E. A. Wolicki—E8
Hornig, D. F.—H1
Inghram, M. G., J. Berkowitz, and W. A. Chupka—Q4
James, H. M.—A1
Johnson, V. A.—K7
Johnson, W. H., Jr. and A. O. Nier—R7
Johnston, W. G. and J. J. Gilman—Y3
Jones, K. W., J. L. Weil, T. H. Kruse, J. A. Baicker, and L. J. Lidofsky—E11
Kaiser, W. and P. H. Keck—C6
Katzman, John—B3
Kerner, Edward H.—N14
Klemens, P. G.—T4
Kraichnan, Robert H.—Q6
Kreger, W. E., H. H. Bolotin, and E. A. Edelsack—E7
Krohn, V. E., T. B. Novey, and S. Raboy—J9
Krone, R. W., A. Everett, and S. S. Hanna—J4
Krzywoblocki, M. Z. v.—N15
Landon, H. H.—X9
Lane, R. O. and J. E. Monahan—X5
Langer, L. M.—V1
Lichtenberg, D. B. and Marc Ross—N9
Livingood, J. J.—W2
Loeffler, F. J.—Z6
Magleby, E. H., J. R. Smith, J. E. Evans, and M. S. Moore—G9
Martin, D. W., S. B. Burson, and J. M. Cork—J5
Maurer, R.—T3
Maurer, R. D.—Y1
Mayer, J. and B. Gossick—C11
McDonald, F. B.—M3
Mihelich, J. W., B. Harmatz, T. H. Handley, and J. J. Pinajian—J10
Montgomery, D. J.—Q1
Moore, M. S., L. G. Miller, and C. W. Reich—G10
Mooring, F. P. and L. L. Lee, Jr.—G6
Morrish, A. H. and William Fuller Brown, Jr.—D7
Munick, R. J.—C3
Murphy, P. G.—E9
Nierenberg, W. A., J. C. Hubbs, H. A. Shugart, H. B. Silsbee, and P. O. Strom—R3
Norbeck, E., Jr.—J3
Novey, T. B.—V2
Nozières, Philippe P.—C5

O'Neill, G. K.—R9
Phillips, J. C.—U1
Picus, G.—T2
Plyler, E. K.—H3
Pond, T. A.—Z9
Porile, Norbert T. and Nathan Sugarman—G12
Powers, R. W.—U2
Rae, E. R. and H. H. Landon—X11
Raz, B. J.—N6
Reitz, John R.—K4
Richardson, J. W.—H4
Sachs, A. M., H. Winick, and B. A. Wooten—Z5
Salzman, George and Freda Salzman—N3
Samios, N. P., J. Steinberger, M. Schwartz, M. Chretien, and J. Leitner—Z1
Saplakoglu, A., L. M. Bollinger, and R. E. Coté—X7
Sargent, C. P., W. Bertozzi, and P. T. Demos—R5
Schiffer, J. P., T. W. Bonner, R. H. Davis, and F. W. Prosser, Jr.—E1
Schindler, A. I. and A. W. Overhauser—L6
Schlömann, Ernst—D3
Schmitt, R. W.—U4
Schwartz, Melvin—B1
Schwartz, R. B., V. E. Pilcher, D. J. Hughes, and R. L. Zimmerman—X12
Schwarzschild, A., B. M. Rustad, and C. S. Wu—N4
Seppi, E. J., B. R. Leonard, Jr., and W. J. Friesen—R11
Shapiro, M. M., B. Stiller, and F. W. O'Dell—B2
Shilts, J. and E. Coomes—L4
Silver, A. H. and P. J. Bray—D9
Silverstein, E., W. Slater, R. Levi-Setti, and V. L. Telegdi—B6
Sladek, R. J.—K10
Slater, W., E. Silverstein, R. Levi-Setti, and V. L. Telegdi—B5
Slepian, J.—Q12, SP1
Smaller, Bernard, Charles Delbecq, and Phillip Yuster—D11
Smith, C. S. and J. R. Reitz—L5
Spiegel, V., Jr., D. O. Oliver, and R. S. Caswell—X8
Spitzer, W. and H. Y. Fan—K6
Stanton, H. E.—Q7
Statz, H., G. A. deMars, L. Davis, Jr., and A. Adams, Jr.—C8
Steinberger, J., N. P. Samios, M. Schwartz, M. Chretien, and J. Leitner—Z2
Stoltzfus, Joseph, Joseph Friichtenicht, and Edward B. Nelson—J2
Symon, Keith—W3
Symon, K. R., P. Stehle, and D. B. Lichtenberg—R13
Thirring, Walter—N8
Thomas, D. G.—Y2
Tobin, R. and J. McElhinney—P10
Tomlinson, E. P.—J6
Tompkins, J. E. and E. G Spencer—D5
Toms, M. Elaine and William E. Stephens—P11
Treuting, R. G.—L2
Tripp, Robert—N1
Troubetzkoy, E. and B. Margolis—N2
Tsai, Yung Su—G4
Turnbull, D. and H. N. Treaftis—L7
Utterback, N. G.—G11
van Vliet, K. M. and J. Blok—C1
Wackerle, J. D. and R. Stump—Z8
Walker, R. M., J. W. Corbett, J. M. Denney, and M. D. Fiske—L12
Walton, R. B., J. D. Clement, and F. Boreli—G2
Warburton, E. K. and J. N. McGruer—E10
Ward, T. J. and J. W. Mihelich—J11
Watkins, G. D. and R. M. Walker—D10
Watt, L. A. K. and A. H. Morrish—D4
Weddell, J. B.—P8
Weinstein, R., S. Ozaki, and A. Wattenberg—P13
Weertman, J.—Y4, SP2
Wellner, Marcel—N11
Werntz, J. H., Jr., and J. R. Dillinger—Y8
Wertheim, G. K. and G. L. Pearson—K2
Wilkinson, P. G.—H2
Winslow, G. H., R. J. Thorn, and R. J. Ackermann—Q5
Wolicki, E. A., H. D. Holmgren, R. L. Johnston, and E. H. Geer—E5
Wolsky, S. P.—C10
Yager, W. A., J. K. Galt, and F. R. Merritt—C4
Yamagata, T., L. B. Auerbach, G. Bernardini, I. Filosofo, A. O. Hanson, and A. C. Odian—Z3
Young, O. B. and T. S. Yoon—B4
Yu, S. P., D. Chen, A. H. Morrish, and W. E. Swanson—D2
Zähringer, J. and E. L. Fireman—R8
Zeidman, B. and J. M. Fowler—E4
Zipoy, D.—P3

Preliminary Announcement of the Meeting in Monterey, California

The **winter meeting** of the American Physical Society **on the west coast** will take place at the U. S. Naval Postgraduate School in Monterey, California on Thursday, Friday, and Saturday, December 27, 28, and 29. We anticipate no trouble with respect to hotel reservations for this meeting. The Monterey Chamber of Commerce Convention Bureau will take care of booking reservations for us. The address is: Mrs. Helen H. Hoxie, Convention Bureau, Box 489, Monterey, California. Motel rooms will be available at the Mark Thomas Inn, just across Fremont Avenue from the Navy School (50 rooms) and at the Casa Munras Hotel (100 rooms). For both of these, single rooms will be $8.00, double $10.00, and twin $12.00. If these are exhausted, the convention bureau will have any number of rooms, up to about 1000, available elsewhere. The Mark Thomas is the only close one. Dormitory housing will be available at Asilomar for $3.00. No difficulty is anticipated for those who do not make advance reservations. Those members who will arrive by plane can have transportation from the airport if they include this request in their reservation.

A meeting of the Northern California Association of Physics Teachers (apparently soon to become a regional section of the AAPT) will be held for one day during the APS meeting. There will be more about this in the Bulletin for the meeting.

There will be a ladies' programme including sightseeing in Monterey and the 17-mile lodge.

The dinner of the Society will be in the Bali Room of the School on Friday night. The principal speaker will be Professor P. Kusch, and the presiding officer will be President Wigner. An innovation will be the presence of an orchestra (which will not add to the cost of the dinner) for dancing after the banquet.

Deadline-date for this meeting is **Friday, October 19.** Abstracts of papers contributed to this meeting must be received not later than this date at the address below.

W. A. NIERENBERG, *Local Secretary for the Pacific Coast*
University of California
Berkeley 4, California

Wanted

The American Physical Society would like to buy the following copies of *The Physical Review* for 1955: January 1, January 15, April 1, July 1,* July 15,* and August 1.* Payment of $1.50 per copy will be made. Copies should be sent to Mr. Wallace Waterfall, American Institute of Physics, 57 East 55th Street, New York 22, New York.

* Issues are especially necessary.

Preliminary Announcement of the 1957 Annual Meeting at New York

The **1957 Annual Meeting** of the American Physical Society will be held in New York, in the Hotel New Yorker and the adjacent Manhattan Center, on Wednesday, Thursday, Friday, and Saturday, January 30 through February 2. **Deadline-date is Friday, November 23:** abstracts of contributed papers must reach the office of the Society not later than that date (address to Karl K. Darrow, American Physical Society, Columbia University, New York 27, New York).

HOTEL INFORMATION

The New Yorker is the headquarters hotel. Reservations should be sent directly to Mr. John Grundhofer, Front Office Manager of the New Yorker, in the manner directed below. Please tear off the attached and use as your room reservation blank. Be sure to specify the persons for whom reservations are being made. All rates quoted are for the room, and in the event of more than one person occupying the room the rate can be shared. If a third person is housed in the room, the cost of the extra "roll-away" bed will be added to the cost of the room.

If a room at the rate requested is not available, one at the nearest available rate will be reserved for you. Be sure to bring the confirmation slip with you as proof of your reservation. In fairness to others, please make a cancellation if your plans change. Unless otherwise requested the hotel will hold reservations only to 6 P.M. of the day of your arrival. Check out time is 3 P.M.

HOTEL RATES

HOTEL	Room and Bath for one per day	Double-Bed Room with Bath for two per day	Twin-Bed Room with Bath for two per day	One Room for 3 persons with bath per day	Suites Living Room Bedroom and Bath for one or two per day
New Yorker 34th Street at 8th Avenue	$8–$12	$10–$15	$13–$18	$15–$18	$25.00 and up

NOTE: All rates subject to New York City 5% hotel room tax.

Tear Off Tear Off

To: FRONT OFFICE MANAGER
HOTEL NEW YORKER
34TH STREET AND 8TH AVENUE
NEW YORK, NEW YORK

A.P.S.

Please enter my reservation for a single / double / twin bedroom at approx. $..... to $..... per day for the 1957 A.P.S. Meeting. I / We plan to arrive ..... and remain until .....

Print below Persons in Your Party

.....
Signature

.....
Address (Street or P.O.)

.....
Town or City and State

MEETINGS AND DEADLINES FOR THE SEASON 1956–1957

Place	*Meeting dates*	*Deadline date*
Chicago	November 23–24	past
Monterey,* California	December 27–28–29	October 19
New York	January 30–February 2	November 23
Norman, Oklahoma	March 1–2	December 28
Philadelphia	March 21–23	January 18, 1957
Washington, D. C.	April 25–27	February 15
Notre Dame, Indiana	June 20–22	April 12
Boulder,* Colorado	September 5–7	to be announced

* Abstracts for the Monterey and Boulder meetings are to be sent to W. A. NIERENBERG, University of California, Berkeley 4, California, and must reach his office not later than the corresponding deadline date.

Abstracts for the other meetings listed above are to be sent to KARL K. DARROW, American Physical Society, Columbia University, New York 27, New York, and must reach his office not later than the corresponding deadline date. Take note that abstracts mailed the day before deadline-day often fail to arrive in time: the last postal delivery of the day usually comes to our office before 2 P.M. Allow at least two days for abstracts sent by air-mail from points east of the Mississippi, and longer for those sent from farther west. To avoid chance of confusion, please do not send an abstract for any meeting until the deadline date of the previous meeting is at least five days past. *The privilege of contributing papers to meetings of the American Physical Society is restricted to the members of the Society and to nonmembers whose papers are sponsored by members.*

RULES PRESCRIBED FOR ABSTRACTS

The Council has ordered that abstracts shall be not longer than two hundred (200) words or the equivalent thereof. In reckoning equivalence, a footnote is equated to ten words; each line in a table to ten words; a "display" formula—one that requires a line to itself—is an expensive luxury equated to forty words.

Two copies of each abstract must be sent to the appropriate office. They must be typewritten and double-spaced; one must be an original, the other may be an original or a carbon copy. Each abstract must be confined to a single page: if it is too long for a single page it is too long to be printed. *Henceforth, if we receive an abstract typed on two pages, we shall print only its first page.* Write each abstract as a single paragraph: the suppression of paragraphs costs time and labor to the editors. Do not use very thin paper; a sheet of very thin paper may cause extraordinary trouble when mixed with sheets of reasonable thickness. Look at the abstracts in this *Bulletin* to see how the title of the paper and the name of the author are to be arranged, and follow the example. Issues of the *Bulletin* are sometimes appreciably delayed because the editors have to do what the authors should have done.

Remember the rule of the Council that, if an author submits more than one abstract, all but one must go onto the Supplementary Programme. In enforcing this rule, an abstract is credited to the author whose name appears first in the by-line. **By action of our Council, abstracts will not henceforth be withdrawn from our proofs unless the asker sends ten dollars with his request.**

Proceedings of the American Physical Society

Minutes of the Summer Meeting on the West Coast Held at the University of Oregon, Eugene, Oregon, June 21, 22, and 23, 1956

THE 1956 summer meeting on the West Coast of the American Physical Society was held at Eugene, Oregon, on Thursday, Friday, and Saturday, June 21, 22, and 23. Our host was the University of Oregon. There was no special occasion for the meeting at Oregon except that it was just 26 years since we last met at Eugene. This meeting was so generally enjoyed that a very commonplace remark became "We must not let another 26 years elapse before returning to Eugene."

There were 16 invited papers and 59 contributed papers. Of the latter, three were read by title. There were no post-deadline papers. One of the more controversial features of the program was the innovation, for which this secretary takes full responsibility, of having essentially no parallel sessions. This resulted in a series of very long days. It was announced in the Bulletin for the meeting as being experimental in nature, and like most experiments turned out to be difficult to interpret, but it can be said that the majority of comments were distinctly favorable. That is, most of those commenting preferred single long sessions to parallel short sessions. However, there was a distinct minority (who were quite vocal) who preferred the conventional procedure.

There were 148 registrations recorded at the meetings. One hundred forty-four bought banquet tickets and 143 actually attended the banquet. This last figure is remarkable because it is perhaps the only time in the recent history of the Society when approximately as many attended the banquet as registered for the meetings. In fact, except for the limitation on seating, more tickets could have been sold for the banquet than people registered for the meetings. The banquet itself was held at the Erb Memorial Union on the campus and was preceded by a cocktail party sponsored by the Department of Physics at the Eugene Hotel. The principal speaker was Professor A. C. Helmholtz on "The Responsibility of Physicists as Educators." Professor R. T. Ellickson presided. In addition, Professor H. D. Smyth and Professor F. Bloch spoke briefly.

W. A. Nierenberg, *Local Secretary for the Pacific Coast*
University of California
Berkeley 4, California

Errata Pertaining to Abstracts A9, C11, E14, and G11 of the 1956 Eugene Bulletin (Series II, Volume 1, No. 5)

A9, by Makoto Takeo. In lines 22–23, instead of "decreases rapidly," read "changes in a complicated way."

C11, by R. A. Bennett, D. J. Donohue, and D. D. Lanning. In line 16, instead of "27.50 ± 0.13," read "26.19 ± 0.3." In line 19, instead of "3.60 ± 0.02," read "3.78 ± 0.05."

E14, by N. F. Wikner, H. A. Bostick, and B. J. Moyer. In lines 19–21, instead of "σ_{total} (mb, $\pm3\%$): Be, 220; C, 316; Al, 674; Cu, 1618; σ_{reaction} (mb$\pm3\%$): Be, 158; C, 218; Al, 396; Cu, 794," read "σ_{total} (mb$\pm4\%$: Be, 230; C, 330; Al, 708; Cu, 1620; σ_{reaction} (mb$\pm4\%$): Be, 158; C, 207; Al, 396; Cu, 780."

G11, by D. D. Betts and G. K. Horton. In lines 10–11, instead of "$a_0=[192f_A+\cdots]/1630$," read "$a_0=[192f_A+\cdots+]/630$."

Minutes of the Summer Meeting in the East Held at New Haven, Connecticut, June 21, 22, and 23, 1956

The 1956 "Summer Meeting in the East" was held in New Haven, Connecticut, at Yale University on June 21, 22, and 23, 1956. This was one of the small, intimate meetings which brought back memories of old times before physics became big. The registration at this meeting was just 400. There were 138 contributed papers and 22 invited papers. The Chairman of the Local Committee, W. W. Watson, had things arranged so that the meeting ran like a well-oiled machine even though he labored under a handicap for the first day because the parcel of Bulletins addressed to him did not arrive. Many members of the Society enjoyed their stay in the dormitories of Silliman College.

A punch party was given on Thursday afternoon by Yale University for the members of the American Physical Society. Unfortunately, the weather was wet, and the party was held in the new linear accelerator building, which—fortunately for the Society—is not yet completely filled with a linear accelerator. The banquet on Friday night had a miserably small attendance of 155. Those who did

not attend the dinner missed a very interesting program. After some introductory remarks by the President, E. P. Wigner, Professor E. C. Pollard gave a very interesting talk, followed by a talk by Professor L. W. McKeehan which has been published in the October issue of *Physics Today*. The weather did not favor the meeting of the Society since it was unfortunately typical of an East Coast summer, being hot and humid. The Society owes a vote of thanks to Professor Watson and Yale University for their hospitality.

W. W. HAVENS, JR.
Deputy Secretary

Elected to Fellowship on June 22, 1956: R. Bowers, G. L. Brownell, J. M. Burgers, J. G. Dash, R. E. Fox, C. Goldberg, Max Goodrich, J. S. Levinger, R. L. Longini, E. W. Mueller, H. T. Nagamatsu, J. A. Sauer, S. A. Schaaf, A. Simon, Rohn Truell, Aaron Wexler, and C. E. Wiegand.

Elected to Membership on June 22, 1956: Charles B. Ackerman, Norman I. Adams, III, [s]E. D. Alyea, Jr., [s]John Philip Andelin, Jr., Arthur G. Anderson, Richard Louis Anderson, Seiya Aramaki, George W. Arnold, Jr., G. Ronald Bainbridge, [s]George Allen Baker, Jr., Willis Herman Barney, Jr., Robert Basile, [s]Sylvan Z. Beer, Peter Leopold Bender, [s]Paul A. Benioff, Emanuel Berger, [s]James D. Bjorken, [s]Lawrence A. Blackwell, [s]Michel A. Bloch, [s]Ronald Blum, Hendrik W. Bode, Norman A. Bostrom, [s]John M. Brabant, [s]Richard Lee Bramblett, Wendell V. F. Brooks, [s]John L. Brown, [s]Gerald P. Calame, William G. Chace, Edward E. Chambers, [s]John Washington Childress, III, John Baptiste Cicchetti, Mason A. Clark, [s]Joseph D. Coccoli, [s]Leonard David Cohen, Martin Allen Cohen, [s]Stuart Alfred Collins, Jr., [s]Charles W. Cook, [s]Neil Duane Cook, [s]John J. F. Corrigan, Norton Cushman, [s]Richard Dalven, Louis Henry Deiterman, Lloyd H. DeVaux, [s]Charles Edward Dickerman, Jean Thomas Dubois, [s]Anthony F. Dugan, Melvin P. Ehrlich, [s]Karl Eklund, Willis Laurens Emery, [s]Ronald Ira Ewing, Clifford Edward Faneuff, Philip M. Fitzpatrick, Joseph A. Fleck, Jr., [s]Billie Lincoln Fletcher, [s]John George Fletcher, [s]William Kent Ford, Jr., [s]R. N. Forrest, [s]Steven C. Frautschi, [s]Jun-ichi Fujita, Martin E. Fuller, II., [s]Louis M. Garrido, Juan Jose Giambiagi, Frank L. Gittler, [s]John Francis Giuliani, John Jacob Glauber, [s]David Jonathan Goerz, Sulamith Goldhaber, [s]Norman Babcock Gove, Daniel E. Grabenstein, [s]Carl Dean Graves, Edward McVitty Greene, [s]Victor Edward Grob, [s]Peter Michael Hall, Thomas C. Hall, Daniel A. Hamlin, [s]Luisa Fernandez Hansen, J. Richard Haskins, [s]Richard A. Hebert, [s]John U. Heckert, [s]John Hess, John J. Hill, [s]Frank Anthony Horrigan, Norman Bennett Humphrey, [s]Farid Hushfar, William L. Imhof, Akira Isoya, Noah R. Johnson, Jr., [s]Walter R. Johnson, [s]Daniel E. Kaplan, Chester S. Kemic, Hans Klemperer, Yoshiyuki Kobayashi, Walter Kofink, Ali Fikret Kortel, Paul Kramer, [s]Edgar Alvin Kraut, Bernard A. Kulp, [s]Joel Louis Lebowitz, [s]Clarence Norman Lee, Jr., [s]Nathan Levine, Richard E. Lingenfelter, [s]Francis Joseph Lombard, Jr., George A. Luce, George Luckey, [s]Cornelius Michael Mahoney, Robert M. Main, [s]August Harold Maki, [s]Gilda Maki, [s]Arthur Gerald Malmon, [s]Richard Marrvs, Francis McCaffrey, [s]David Keith McDaniels, [s]Carl Edwin McIlwain, John Philip McKelvey, Joseph Meixner, M. A. duT. Meyer, [s]Mark G. Miksic, Alfred Milch, [s]Dean Lewis Mitchell, George L. Montet, Willis E. Moody, Jr., M. N. Moore, [s]Thomas G. Moore, [s]Robert William Motley, [s]Joseph Timothy Mullhaupt, [s]Joe H. Mullins, Thomas P. Murray, [s]Gerry Neugebauer, William Elbert Nexsen, Jr., Van Olin Nicolai, [s]Thomas G. Nilan, N. Vivien Nininger, Jr., [s]Harris A. Notarys, Giuseppe Paolo Occhialini, Stanislaw Olbert, Edward Paul Palmer, Fred W. Paul, Norman E. Pentz, [s]Peter Silas Pershan, [s]Peter Pesch, [s]Walt Petersen, Peter Roderick Phillips, [s]Joel David Pincus, David Polur, Ira P. Pratt, Jr., [s]Hubert J. Reeves, Robert C. Rempel, Gunter H. Richter, [s]Paul Wesley Ridenour, [s]Jerome William Riese, Michel Riou, Rudolph Oscar Robinson, [s]A. Auriol Ross, [s]James J. Rowley, Norio Ryu, David Sacher, Jumpei Sanada, [s]James Joseph Schmidt, [s]John Wilfred Schultz, Edward E. Schwenzfeyer, Antonio Scortecci, [s]G. R. Screaton, Pierce W. Selwood, Robert W. Sharp, [s]Yoshihisa Shimura, Zensaku Shirogane, [s]Alexander Joseph Shuskus, Phyllis Elizabeth Stello, William H. Storey, Jr., [s]Richard L. Strombotne, David A. Swick, [s]Willard Lindley Talbert, Jr., [s]Dale T. Teaney, [s]Terence Christopher Terman, V. Paul Vadopalas, Shirley D. Vickers, [s]Samuel Martin Vidulich, Robert C. Vik, [s]Charles Norman Vittitoe, [s]Dirk Walecka, J. Torkel Wallmark, G. King Walters, James W. Ward, Theodore Watanabe, A. Carl Westbom, Don M. Wheeler, [s]Alwyn Frederick Wiebe, [s]E. Gordon Wikner, G. Theodore Wood, [s]Jack Yahia, Agusto Ybarra, [s]Harry Dopson Youmans, Jr., [s]Theodore Francis Zipf.

[s] Student.

Errata Pertaining to Abstracts F5 and R2 of the 1956 New Haven Bulletin (Series II, Volume 1, No. 6)

F5, by R. J. Sladek. In line 15, instead of "$\tau \sim \epsilon^{\epsilon}$," read "$\tau \sim A\sigma^{-1}+\epsilon^{\epsilon}$." In lines 20–21 instead of "InAs, $m^*/m_0 = 0.0020 \pm .0005$," read "InAs, $m^*/m_0 = 0.020 \pm 0.005$." In lines 21–22, instead of "The former result is quite unexpected;" read "The former result is somewhat lower than obtained by other indirect methods;".

R2, by A. H. Armstrong, L. Rosen, and L. Stewart. In line 5, instead of "22-kev deuterons" read "220-kev deuterons." In line 9, instead of "circule," read "circle." In line 14, instead of "where $\sigma(E)$ is in millibarns/Mev," read "where $\sigma(\mathbf{E})$ is in barns/Mev."

MINUTES OF THE MEETING OF THE DIVISION OF FLUID DYNAMICS HELD AT THE CALIFORNIA INSTITUTE OF TECHNOLOGY, PASADENA, CALIFORNIA, MARCH 19, 20, AND 21, 1956

THE meeting of the Division of Fluid Dynamics in Pasadena was held at California Institute of Technology, March 19, 20, and 21, 1956, and was followed by a visit to the Scripps Institution of Oceanography, La Jolla, California, on March 22. Local arrangements were made by P. P. Wegener and his Organizing Committee and the Programme Committee was headed by H. W. Liepmann. The programme included 5 invited papers and 34 contributed papers as appear below.

The participants were welcomed by C. B. Millikan, Director of the Guggenheim Aeronautical Laboratory. Monday evening the participants visited the Jet Propulsion Laboratory where they were welcomed by W. H. Pickering, Director of the Laboratory. The dinner of the Division on Tuesday was followed by an address given by Otto Laporte who talked on Science in the State Department. On Wednesday afternoon the participants visited the fluid dynamics laboratories of the Guggenheim Aeronautical Laboratory. The tour of the Scripps Institution of Oceanography was arranged by Robert S. Arthur and included the following informal talks on: **Waves and the Formation of Sand Ripples,** by Douglas Inman; **Observations of the Nuclei of Cavitation,** by Leonard Liebermann; **Optical Measurements of the Sea Surface,** by Charles Cox; **Periodic Variation of Sea Level Related to Passage of Waves in the Easterlies,** by Gordon Groves; and the **Tsunami Problem,** by Walter Munk.

Robert N. Hollyer, Jr., recently appointed assistant-secretary of the Division, was particularly helpful in the various phases of the organization of the meeting.

FRANÇOIS N. FRENKIEL, *Secretary-Treasurer*
Division of Fluid Dynamics
American Physical Society

PROGRAMME

Shock Wave Problems

(S. A. SCHAAF presiding)

Contributed Papers

A1. Preliminary Studies of the Growth of Turbulent Flows Following Shock Wave Passage through a Narrow Duct.* JOHN ALLPORT,† *Princeton University* (introduced by D. Bershader).—Shock waves were allowed to pass through a channel of cross section $4\times\frac{1}{4}$ in. Observations by interferometry, Schlieren photography, and thin film surface thermometry show the laminar boundary layer and its transition to turbulence, followed by closure of the "potential wedge" and the growth of fully developed turbulent flow. Transition Reynolds numbers have been calculated in a few cases. Velocity profiles obtained from density measurements in the fully developed turbulent region appear to agree with a $\frac{1}{7}$th power law. The existence of fully developed channel flow and the magnitude of the turbulent skin friction and heat transfer have been inferred from the temperature—time records of the thin film thermometer.

* Supported by the Office of Naval Research.
† Now at Convair, San Diego.

A2. Spherical Blast Waves in Air.* HAROLD L. BRODE, *The RAND Corporation, Santa Monica.*—Properties of spherical shock waves in air such as the pressure, density, particle velocity, temperature, internal energy, and dynamic pressure all as functions of time and space are available from solution of the partial differential equations of gas motion. Solution was accomplished by numerical integration of these equations on a high-speed computer. These solutions differ in several respects from previous calculations for an ideal gas,[1] most markedly in the temperatures, densities, and dynamic pressures. The nonideal properties of air, as expressed in a detailed fit to the equation of state for air, have the effect of reproducing the observed decay rates of spherical blasts in air, dependent only on the initial conditions and without arbitrary energy normalizations.

* This work was supported jointly by the U. S. Air Force and the U. S. Atomic Energy Commission.
[1] H. L. Brode, J. Appl. Phys. **26**, 766–775 (1955).

A3. Inviscid Hypersonic Flow over Blunt-Nosed Slender Bodies.* LESTER LEES, *California Institute of Technology.*—At hypersonic speeds the drag/area of a blunt nose is much larger than the drag/area of a slender afterbody, and the energy contained in the flow field in a plane at right angles to the flight direction is nearly constant over a downstream distance many times greater than the characteristic nose dimension. The transverse flow field exhibits certain similarity properties directly analogous to the flow similarity behind an intense blast wave found by G. I. Taylor and S. C. Lin. Conditions for constant energy show that the shape of the bow shock wave $R(x)$ not too close to the nose is given by $R/d=K_1(\gamma)(x/d)^{\frac{1}{2}}$ for a body of revolution, and by $R/d=K_0(\gamma)(x/d)^{\frac{1}{2}}$ for a planar body, where d is nose diameter, or leading-edge thickness. A comparison with the experiments of Hammitt, Vas, and Bogdonoff on a flat plate with a blunt leading-edge at $M_\infty=13$ in helium shows that the shock-wave shape is predicted very accurately by this analysis. The predicted surface pressure distribution is somewhat less satisfactory. Energy considerations combined with a detailed study of the equations of motion show that flow similarity is also possible for a class of bodies of the form $r_b\sim x^m$, *provided* that $m'\leq m\leq 1$ where $m'=\frac{3}{4}$ for a planar body and $m'=\frac{3}{2}(\gamma+1)/3\gamma+2$ for a body of revolution. When $m<m'$, the shock shape is not similar to the body shape, and except for the constant energy flows the entire flow field some distance from the nose must depend to some extent on the details of the nose geometry.

* The work discussed in this paper was carried out under the sponsorship and with the financial support of the Office, Chief of Ordnance, and the Office of Ordnance Research, U. S. Army.

A4. Propagation of Shock Waves in Nonuniform Gases. T. P. MITCHELL, *California Institute of Technology* (introduced by M. S. Plesset).—The one-dimensional propagation of shock waves in a perfect gas in which the pressure and the density are not necessarily uniform is investigated by seeking similarity solutions of the equations describing the nonisentropic motion of the gas. It is shown that such solutions can be found and that they can be related to specific types of compressive piston motion. In particular, the shock resulting from the uniform compressive motion of a piston in a nonuniform gas is studied. Analytic results are obtained for a gas in which the pressure is constant but the density varies and for which the ratio of the specific heats is $\frac{3}{2}$. Numerical solutions are presented for situations in which both the pressure and the density are variable. Solutions are more difficult to obtain for the nonuniform motion of a piston but some details are given in the case of a decelerated piston motion.

A5. Properties of Liquids in Strong Shock Waves.* M. H. RICE AND J. M. WALSH, *Los Alamos Scientific Laboratory*.—A high-speed photographic method was used to obtain pressure-compression points for explosive-induced shock waves in liquids. Hugoniot curve data have been obtained for water, mercury, and thirteen other organic liquids in the pressure range 30 to 450 kilobars. For water, additional thermodynamic information obtained from a shock-reflection technique has been used to formulate a complete equation of state in the pressure range 25 to 250 kilobars. This equation of state was used to calculate isotherms and adiabats neighboring the Hugoniot curve and to calculate other quantities of thermodynamic and hydrodynamic interest.

* Work done under the auspices of the U. S. Atomic Energy Commission.

A6. Aftereffect of an Explosion.* P. RUDNICK AND V. C. ANDERSON, *Scripps Institution of Oceanography* (introduced by F. N. Spiess).—Certain low-level acoustic phenomena are described which have been observed to follow closely an explosion of a small TNT charge at or a few meters below a water surface, coming to an abrupt conclusion 6 to 25 msec after the explosion. The pressure level is about 30 db below the initial shock and the source of the secondary disturbances appears to coincide with the site of the explosion to within about one meter. No adequate interpretation has been made

* This work represents one of the results of research carried out under contracts with the Bureau of Ships, Navy Department.

A7. A New Governing Equation of Shock Analysis with Heat Transfer in Polyatomic Gases.* PHRIXOS J. THEODORIDES, *University of Maryland*.—In shock analysis, steep gradients of temperature and high divergence of the velocity vector seem to invite a widening of the viscosity concept for polyatomic gases by dropping the Stokes' hypothesis, and including nonlinear friction. Symmetrical stress matrices are developed with three independent physical parameters of gas friction, *viz.*, one of linear bulk viscosity and one each of linear and nonlinear shear viscosity. The conservation equations for mass, momentum, and energy are set for triaxial, laminar supersonic flow of an isotropic, compressible, viscous, and heat-conducting gas. These relations are combined with the state equation, transformed, and specialized for uniaxial, steady flow. Thus a new governing equation of shock analysis is derived. The integration is discussed for temperature effects upon all three viscosity parameters, the heat conductivity, and specific heats. Though explicitly continuous, the present theory is implicitly linked to kinetic theory in expressing accordingly most of the physical parameters. Then, quantum dynamics hold, for $T \geq 600°K$, as to energies in vibrational modes with proper frequencies and overtones from spectrometry. For nonlinear damping, no empirical data of separation are so far available. But the expediency is open to fill up, after Gilbarg and Paolucci, with molecular Burnett numbers of third approximation as based on Sonine polynomials.

* This work is part of an investigation sponsored by the U. S. Air Force, through the Office of Scientific Research of the Air Research and Development Command.

A8. Spectral Line Profiles in the Luminous Shock Tube.* E. B. TURNER, *The University of Michigan*.—Although several investigators have observed the spectra of luminosity behind very strong shock waves, none have previously obtained quantitative data on spectral line shapes. Spectral observations were made at the end of the shock tube where the temperatures are somewhat higher than behind the primary shock wave. This has made necessary a theoretical and experimental explanation of the hydrodynamic processes at the end of the tube, namely, the interaction of the reflected shock with the interface. A revolving drum camera was used with a spectrograph to obtain time-resolved spectra of the luminosity. A new film calibration method was devised to eliminate the difficulties with reciprocity law failure, and the intensity profiles derived therefrom are fairly accurate. Shock waves were produced in neon, to which about 1% hydrogen was added. Profiles of the H_β line of hydrogen were obtained and found to be slightly wider than predicted by the Holtsmark theory, but in better agreement with the recent Kolb theory.[1] The conditions behind the first reflected shock, as calculated from the primary shock velocity which was measured with a wave-speed camera, were approximately: $T = 12\,000°K$, ion density $= 1.5 \times 10^{16}$ ions per cc.

* This research was supported by the U. S. Air Force through the AF Office of Scientific Research, Air Research and Development Command.

[1] Alan C. Kolb, Bull. Am. Phys. Soc., Ser. II, 1, 22 (1956).

Magnetohydrodynamics, etc.

(TH. VON KÁRMÁN presiding)

Invited Papers

B1. Induction Effects Appearing When a Shock Wave Moves through a Conducting Gas in a Magnetic Field. J. M. BURGERS, *University of Maryland*. (30 min.)

B2. Some Aspects of the Structure of Magnetohydrodynamic Shocks in the Limit of No Particle Collisions. STIRLING A. COLGATE, *Radiation Laboratory, University of California*. (30 min.)

B3. Nonstationary Strong Shock Waves. SEBASTIAN VON HOERNER, *Mount Wilson and Palomar Observatories*. (30 min.)

Contributed Papers

B4. Gaseous Afterglows in the Visualization of Low Density Flows.* FRANKLIN C. HURLBUT AND WULF B. KUNKEL, *University of California, Berkeley*.—Techniques are described for the use of air, nitrogen, argon, and helium afterglows under appropriate flow conditions in the visualization of low density flows to Mach 4. Photographs of shock waves and other flow structures are discussed and factors influencing quantitative interpretation are described.

* This work was supported by the U. S. Air Force.

B5. Quantum Mechanical Effects in Gas Dynamics. E. V. LAITONE, *University of California, Berkeley*.—Recent analytical studies by Morgenstern have indicated that the Boltzmann equation, describing the kinetic theory of a rarefied gas, cannot predict general spatially nonhomogeneous solutions. Morgenstern proposed a modified collision integral that can provide more general solutions but still reduces to that of Boltzmann for the spatially homogeneous case. The present paper points out that this proposed collision integral can be

made physically plausible by introducing recent developments in the quantum mechanical studies of transport processes. It is also pointed out that when the higher order corrections beyond the Navier-Stokes order of approximation are to be considered, then the density-dependent symmetry effects due to Bose-Einstein statistics, and other quantum mechanical effects, in addition to the introduction of the scattering cross section, may have to be included.

B6. Experimental Isentropic Flow Relations in High-Energy Air. D. BLOXSOM, JR., *ARO, Inc., Tullahoma.*—Air has been produced at stagnation enthalpies of 4.73×10^7 to 2.26×10^8 ft ^{2}/sec^2 for sufficiently long times (5.2 to 0.5 msec) to permit the study of isentropic nozzle expansions. Density and pressure measurements establish stagnation conditions and area ratio and static pressure measurements establish conditions after expansion of the flow. The experimental results are compared with theoretical calculations of the isentropic expansion of air in this energy range.

B7. Study of Fast Chemical Rate Processes in Supersonic Flow.* PETER P. WEGENER, *California Institute of Technology.*—At hypersonic speeds, temperatures in the flow around objects reach values at which components of air may be dissociated. The attending change of local enthalpy will affect aerodynamic parameters. It is very difficult to duplicate these effects in air flow in laboratory experiments. Basic studies may be carried out using substitute gases which exhibit rapid chemical transformation at lower temperatures and Mach numbers. It is shown that supersonic nozzle flow with a chemically inert carrier gas, and small added amounts of reacting species may be applied to dissociation studies in flow over simple bodies. This method is at the same time a new tool for the study of rapid chemical reactions. Nozzle expansions involving equilibrium and time dependent reactions of the nitrogen tetroxide-dioxide system carried in inert nitrogen will be discussed theoretically. The time resolution of the expansion process is about that of the shock-tube method,[1] while the entire flow system is time invariant and therefore amenable to study by conventional methods such as pressure and absorption measurements.

* Research done under the joint sponsorship of the Department of the Army, Ordnance Corps, and the Department of the Air Force.

[1] T. Carrington and N. Davidson, J. Phys. Chem. **57**, 418 (1953).

Various Fields of Fluid Dynamics

Invited Paper

C1. Equations of Motion of a Stratified Fluid. CARL ECKART, *Scripps Institution of Oceanography.* (30 min.)

Contributed Papers

C2. Studies of Boundary Layer Slip Solutions and Alden's Method for Boundary Layer Correction. STOUGHTON BELL, II, *Sandia Corporation* (introduced by E. F. Cox).—Two aspects of incompressible laminar boundary layer flow on a semi-infinite flat plate at zero incidence are discussed. Firstly, Alden's proposed scheme of solution of the Navier-Stokes equations for this problem is demonstrated to be invalid, inasmuch as the boundary conditions in the free stream cannot be satisfied to all orders. Secondly, an account is given of the effect of a velocity slip boundary condition on the solution of the Oseen boundary layer equations for the same problem. It is found that an additional nonuniformity in the solution is caused by the introduction of slip.

C3. Effect of Fluid Dynamic Time Lags in Recording Continuously Varying Pressures. J. M. KENDALL, *U. S. Naval Ordnance Laboratory.*—The system considered consists of a long tube of small diameter connected between the source of varying pressure and a fixed volume pressure gauge. Such a system, making use of a moving probe, is used in taking continuous calibrations of wind tunnels. The probe should move with the fastest speed possible which will not cause undue distortion of wave shapes of pressure variations. Since these variations are usually a small percentage of the prevailing pressure, linear theory may be used. A Fourier integral analysis shows that if the probe moves extremely slowly, no distortion results. As the probe speed is increased, the distortion noticed is a simple delay or displacement of the pressure wave shapes. Further speed increase not only increases delay but distorts shapes of waves with considerable loss of detail. A simple mathematical expression is given which indicates the amount of distortion with various speeds. A ready-reference chart, giving maximum speeds as a function of tube length and inside diameter, prevailing pressure, volume of the pressure gauge, and accuracy required, has been prepared.

C4. Measurements of Heat Transfer from Wires in Supersonic Flows. JOHN LAUFER AND ROBERT MCCLELLAN, *Jet Propulsion Laboratory, California Institute of Technology.*—The abstract of this paper appeared by error in a previous issue [Bull. Am. Phys. Soc., Ser. II, 1, 227 1956)].

C5. Recovery Factors for Spheres at Low Reynolds Number.* S. A. SCHAAF AND S. F. MACK, *University of California, Berkeley.*—The thermal recovery factor for the forward stagnation point of a sphere in incompressible flow is calculated for the case of low Reynolds number and Prandtl number of $\frac{3}{4}$. It is shown that the recovery factor is greater than unity. These results show a trend which is in agreement with the limiting case of free molecule flow, and also with experimental data.

* This work was jointly supported by the Office of Naval Research and the Air Force.

C6. Lift on Flat Plates in Low Density Supersonic Flow.* D. M. TELLEP AND L. TALBOT, *University of California, Berkeley* (introduced by S. A. Schaaf).—Normal forces on rectangular flat plates in supersonic, rarefied flow were measured over the range $228 \leq R \leq 2412$ and $3.69 \leq M \leq 4.12$ at angles of attack up to eight degrees. Weak interaction theory was used to derive a simple expression for the normal force and was found to predict the order of magnitude of the increased normal force as well as the trend of the normal force with Reynolds number.

* This work was jointly supported by the Office of Naval Research and the Air Force.

C7. Rayleigh's Problem at Low Mach Number According to the Kinetic Theory of Gases.* H. T. YANG AND LESTER LEES, *California Institute of Technology.*—Rayleigh's problem of an infinite flat plate set into uniform motion impulsively in its own plane is studied by using Grad's equations and boundary conditions developed from the kinetic theory of gases. For a heat-insulated plate with a small impulsive velocity (low Mach number), only flow velocity, shear stress, and energy (heat flux) parallel to the plate are generated, while pressure, density, and temperature of the gas remain unchanged. Moreover, no normal velocity, normal stress, or normal energy flow is developed. Near the start of the motion the flow behaves like a free molecular one, and as time goes on the flow approaches the classical Rayleigh's result. Approximate closed-form solutions valid for all values of the time (all Reynolds numbers) are obtained.

* The work discussed in this paper was carried out under the sponsorship and with the financial support of the Office, Chief of Ordnance, and the Office of Ordnance Research, U. S. Army.

Hydrodynamics

Contributed Papers

D1. A Note on Partial Cavitation of Flat Plate Hydrofoils.* A. J. ACOSTA, *California Institute of Technology* (introduced by M. S. Plesset).—Tulin and Wu have treated the problem of fully developed cavitation on flat plate and cambered foils. In these works, the length of the cavity is always greater than the chord of the hydrofoil, and the cavity is assumed to start at the leading edge of the plate. In this study, use is made of Tulin's linearized procedure to treat the case of partial cavitation, i.e., when the cavity length is less than the chord. It is found that the cavitating lift is greater than the noncavitating lift by an amount roughly proportional to the square of the angle of attack divided by the cavitation number. These results account for the observed increase of lift coefficient on partially cavitating sharp-edged hydrofoils and pump blades. However, the theory is limited to cavity lengths less than about four-tenths of the chord.

* This work was supported by the Office of Naval Research.

D2. Application of Ship Wave Theory to the Hydrofoil of Finite Span. JOHN P. BRESLIN, *Stevens Institute of Technology* (introduced by B. K. Erdoss).—It is demonstrated in this paper that the deep water wave drag of a hydrofoil of finite span can be found directly from the theory developed largely for ship hydrodynamics by Havelock and others. The wave drag is then studied at high Froude numbers, and from the observed behavior the induced drag of the hydrofoil can be deduced from existing aerodynamic formulas. Evaluation of the resulting formulas is effected for two arbitrary load distributions and a comparison with some model test results is made. A practical approximation which gives the influence of gravity over a range of high Froude numbers is found, and from this one can deduce a span Froude number beyond which the effects of gravity may be ignored. It is also shown that an expression for the waves at some distance aft of the hydrofoil can be deduced from the general formulas developed for ship hydrodynamics. A discussion of the wave pattern is given with particular emphasis on the centerline profile at high Froude numbers and a contrast is pointed out in regard to the results of the two-dimensional theory for the hydrofoil waves and wave resistance.

D3. A Study of Transient Strains in a Photoelastic Plastic Resulting from Cavitation Bubble Collapse.* A. T. ELLIS, *California Institute of Technology.*—A photographic system using a Kerr cell light shutter has been developed to provide sequences of up to 700 photoelastic pictures at 1 μsec intervals. This equipment has been used to photograph cavitation bubbles in water collapsing on the surface of a photoelastic solid. The observed fringe pattern is axially symmetric about the point of bubble collapse, and therefore quantitative information on the forces involved may be obtained if the dynamic behavior of the plastic is known. Experiments to determine the dynamic photoelastic characteristics of the material CR-39 have been carried out over a wide frequency range. From these results a direct measurement of cavitation forces and their time duration has been made. This information is consistent with observed damage to metals and to records obtained from piezoelectric materials.

* This work was supported by the Office of Naval Research.

D4. Collapse of a Spherical Bubble in a Compressible Liquid.* F. R. GILMORE, *The RAND Corporation.*—With the help of an approximation first proposed by Kirkwood and Bethe, the partial differential equations for the flow of a compressible liquid surrounding a growing or collapsing spherical bubble have been reduced to a single ordinary differential equation for the bubble-wall velocity. In the case of a bubble collapsing with a constant internal pressure, an explicit solution is obtained which shows that the velocity varies like $R^{-\frac{1}{2}}$ as the bubble radius R approaches zero, instead of the R^{-1} variation given by incompressible theory. To test the validity of this approach, the exact compressible flow equations were integrated numerically on an electronic computer, using an approximate equation of state for water and a constant collapsing pressure of 1 atmos. The numerical values for the bubble-wall velocity agree with the approximate solution within 5%, up to a collapse velocity of 5 times the velocity of sound in the liquid, where the numerical calculations were stopped. The present theory has also been applied to the collapse and rebound of a gas-filled bubble.

* Most of this work was done while the author was at The California Institute of Technology, and was supported by the Office of Naval Research.

D5. Measurement of Vorticity Components in Turbulent Liquid Flows. L. M. GROSSMAN AND HUON LI, *University of California, Berkeley* (introduced by S. A. Schaaf).—Recent tentative theories of the origin of turbulence and the mechanics of turbulent shear flows have focused attention upon the vorticity in such flows. A method is described for the measurement of the local root mean square values of the fluctuating components of vorticity in turbulent liquid flows. The principle of the method is based upon the induction of an electrical potential field in a conducting continuum in motion relative to a fixed and uniform magnetic field. It is shown that the electrical potential φ is related to the vorticity $\boldsymbol{\Omega}$ and the magnetic field intensity $\mathbf{B}$ by the Poisson equation $\nabla^2\varphi = \mathbf{B}\cdot\boldsymbol{\Omega}$. By suitable arrangement of an electrode probe in the form of a small cross it is possible to measure the rms values of the local derivatives of the potential gradient which enable computation of the vorticity components in a known magnetic field.

D6. Drag of Dihedral Hydrofoils below a Free Surface. PAUL KAPLAN, *Stevens Institute of Technology.*—The total drag (induced and wave-making) of finite-span dihedral hydrofoils moving at high speed below a free surface is derived in this paper. The potential of the foil in an infinite fluid is represented by a continuous distribution of doublets, and the wave drag of this distribution is determined by application of results given by Havelock and Lunde for ship wave problems. The limiting behavior of the wave drag at high speeds is used to identify the form of the induced drag, based on the requirements dictated by the boundary conditions and the results found for flat horizontal hydrofoils and vertical struts. The results are given in integral form, to be evaluated for an arbitrary circulation distribution which is to be specified.

D7. Forces, Moments, and Added Masses for Rankine Bodies.* L. LANDWEBER AND C. S. YIH, *Iowa Institute of Hydraulic Research.*—The dynamical theory of the motion of a body through an inviscid and incompressible fluid has yielded three relations: a first, due to Kirchhoff, which expresses the force and moment acting on the body in terms of added masses; a second, initiated by Taylor, which expresses added masses in terms of singularities within the body; and a third, initiated by Lagally, which expresses the forces and moments in terms of these singularities. The present investigation is concerned with generalizations of the Taylor and Lagally theorems to include unsteady flow and arbitrary translational and rotational motion of the body, to present new and simple derivations of these theorems, and to compare the Kirchhoff and Lagally methods for obtaining forces and moments. In comparison with previous generalizations, the Taylor theorem is derived when other boundaries are present; for the coefficients due to rotation alone, for which no relations were known, it is shown that these relations do not exist, in general, although approximate ones are found for elongated bodies. The deriva-

tion of the Lagally theorem leads to new terms, compact expressions for the force and moment, and the complete expression of the forces and moments in terms of singularities for elongated bodies.

* Research sponsored by the Office of Naval Research.

D8. A Note on the Cavity Flow Past a Hydrofoil in a Liquid with Gravity.* B. R. PARKIN, *California Institute of Technology* (introduced by M. S. Plesset).—The effects of gravity upon the full cavity flow past a flat plate hydrofoil are examined by extending Tulin's linearized theory of cavity flows. In general, these effects are appreciable only in the case of low Froude number flows, and the present theory applies only to those flows in this Froude number range for which the effects of gravity may be regarded as being of the first order. The method used is not capable of giving a complete description of cavity flows with large buoyant effects. In the present case, it is found that the influence of gravity on the hydrofoil lift coefficient varies as the reciprocal of the square of the Froude number based on the profile chord.

* This work was supported by the U. S. Navy Bureau of Ships through the David Taylor Model Basin.

D9. A Note on the Linear and Nonlinear Theories for Fully Cavitated Hydrofoils.* T. YAO-TSU WU, *California Institute of Technology* (introduced by M. S. Plesset).—In the present investigation the linear theory for the fully cavitated flat plate which was recently given by Tulin is extended to calculate the hydrodynamic lift and drag on a fully cavitated hydrofoil of arbitrary camber with any cavitation number. A numerical example is given for a circular arc hydrofoil subtending an arc angle of 16°. A nonlinear theory for the same lifting problem of fully cavitated hydrofoils has been developed recently by the author based on free streamline theory. Two examples calculated explicitly with this nonlinear theory are the flat plate and the circular arc hydrofoils. A direct comparison between these two theories shows that the linearized solution gives larger values of lift and drag than the nonlinear solution. The discrepancy between the two solutions for the lift and drag increases with increasing angle of attack. For the flat plate, the difference exceeds 18% for attack angle higher than 10°. With the additional effects of camber the difference between the two solutions increases with increasing camber.

* This work was supported by the Office of Naval Research.

Dinner of the Division of Fluid Dynamics

(CLARK B. MILLIKAN presiding)

Address: Science in the State Department. Otto Laporte, University of Michigan.

Boundary Layer, Turbulence, etc.

(L. M. K. BOELTER presiding)

Invited Paper

E1. Effect of Roughness on Turbulent Skin Friction. FRANK E. GODDARD, JR., *Jet Propulsion Laboratory, C.I.T.* (30 min.)

Contributed Papers

E2. A Double Series Expansion Method for the Viscous Flow Flat Plate Problem.* JOHN A. LAURMANN, *University of California, Berkeley* (introduced by S. A. Schaaf).—A proposal for solving the incompressible viscous flow about a semi-infinite flat plate is discussed. The method employs two expansions in ascending powers of the viscosity, one for the "external" flow, and another for the flow near the plate surface. The success of this technique, in contrast to other methods of series solution, is demonstrated for the linearized case.

* This work was jointly supported by the Office of Naval Research and the Air Force.

E3. Turbulent Wake of a Thin Airfoil at Low Speeds. GEORGE S. CAMPBELL, *California Institute of Technology* (introduced by H. W. Liepmann).—Experiments have been made to determine the nature of turbulence in the wake of a two-dimensional airfoil at low speeds. The experiments were motivated by the need for data which can be used for analysis of the tail-buffeting problem in aircraft design. Turbulent intensity and power spectra of the velocity fluctuations were measured at a Reynolds number 1.5×10^5 for several angles of attack. Total-head measurements were also obtained in an attempt to relate steady and fluctuating wake properties. Mean-square downwash was found to have nearly the same dependence on vertical position in the wake as that shown by total-head loss. For this particular wing, turbulent intensity, integrated across the wake, increased roughly as the $\frac{3}{2}$ power of the drag coefficient. Power-spectrum measurements indicated a decrease in frequency as wing angle of attack was increased. The average frequency in the wake was found proportional to the ratio of mean wake velocity to wake width.

E4. On a Problem in Aerodynamic Acoustics. G. M. CORCOS AND H. W. LIEPMANN, *Douglas Aircraft Company and California Institute of Technology.*—Consider an elastic plate which separates fluid in motion from fluid at rest. Turbulent flow exerts pressure fluctuations upon the boundary, and hence the plate is exposed to forces which are random in space and time. The plate will vibrate and thus radiate sound into the fluid at rest. This problem is the simplest model for the sound produced inside an airplane cabin due to the flow past the outside of the fuselage. The pressure fluctuations are characterized by a correlation function or a power spectrum $\Phi(\omega,k)$ in frequency ω and wave number k. For the plate a generalized admittance $\Gamma(\omega,k)$ can be defined by the methods of Liepmann.[1] The intensity of the sound field in the fluid at rest thus can be related to the pressure fluctuations by generalized harmonic analysis. If one makes the simplest assumption concerning the pressure field, i.e., that the free stream velocity U, density ρ, and the boundary layer thickness δ are the only characteristic parameters, one finds that the acoustic intensity in the fluid at rest varies approximately as the first power of the boundary layer thickness and as the fifth power of the velocity. Thus the boundary layer contributes to airplane cabin noise a part which increases rapidly with speed but which is little affected by boundary layer thickness.

[1] H. W. Liepmann, Z. Appl. Math. Phys. 3, 321.

E5. On the Influence of Turbulence on the Transfer of Heat Across a Boundary Layer.* J. KESTIN AND P. F. MAEDER, *Brown University* (introduced by R. B. Lindsay).—Two series of experiments are described in which the influence of turbulence intensity on the local rates of heat transfer was investigated at Reynolds numbers near the critical. First, a tube provided with two tripping wires was placed in a transverse stream in a wind tunnel whose turbulence was varied by the insertion of suitable screens. At a given Reynolds number the laminar and turbulent portions of the boundary layer and the width of the wake were kept independent of the free-stream turbulence. The results show that the local Nusselt numbers are strongly affected by the intensity of turbulence. For example at $\langle Re\rangle_{hy}=170\,000$ a change in intensity from 0.9% to 2.6% produces a change of 25% in the over-all Nusselt number. Secondly, local measurements at the stagnation point of a circular cylinder in cross flow are reported. A change in intensity from about 1% to about 3% changes the local Nusselt

number by 50% to 60% and yields values which are higher than Squire's theoretical values. The experimental results show conclusively that the temperature profile, and probably also the velocity profile, in a laminar boundary layer are strongly influenced by the external turbulence.

* The work described in this paper was carried out under the sponsorship of the National Advisory Committee for Aeronautics.

E6. The Solution of Tricomi's Equation for a Transonic Jet. Y. K. PIEN, *Virginia Polytechnic Institute* (introduced by T. M. Hahn).—The boundary value problem of a transonic jet formulated in the hodograph plane is to solve the Tricomi's equation, $u_{xx}-xu_{yy}=0$, in both subsonic (elliptic) and supersonic (hyperbolic) regions. It is known that this problem involving the mixed-type equation can be reduced to a purely elliptic type. Since the general solution is available in the hyperbolic region, a functional relation between the stream function and its derivative can be formed along the sonic line and serves as an additional condition for the flow in the elliptic region. However, a direct approach proved to be still difficult. This difficulty is overcome by constructing another functional relation based on the boundary conditions in the elliptic region. The two functional relations which must be compatible enable us to determine either the stream function or its derivation on the sonic line. Consequently, the original problem is reduced to an inversion of a singular integral equation of the Cauchy type. The inversion is carried out by using Carleman's method, which is to transform the singular integral equation into a Hilbert (Riemann) problem.

E7. Negative Magnus Force. E. KRAHN, *Naval Ordnance Laboratory* (introduced by J. M. Kendall).—On rotating spheres, cylinders, and other bodies of revolution, negative Magnus forces have been observed sometimes. We will consider here the case of an infinite cylinder in cross flow, i.e., the two-dimensional problem, and explain the occurrence of the negative magnetic force (M.f.) by the different character of the boundary layer on the upper and lower side of the rotating cylinder. It can happen that the boundary layer is laminar on one side of the cylinder and turbulent on the other and is attached longer on the lower side of the cylinder. In this case a negative M.f. will occur. Besides this qualitative explanation, quantitative statements are made which show the dependence of the appearance of the negative M.f. on the Reynolds number and the spin ratio of the cylinder. Some more or less abrupt changes of the M.f., even in cases when it is positive, can be explained.

E8. Measurement of Recovery Factors and Heat Transfer Coefficients with Transpiration Cooling in a Turbulent Boundary Layer at $M=3.0$.* BERNARD M. LEADON AND CHARLES J. SCOTT, *University of Minnesota*.—Recovery factor and steady-state heat transfer measurements were made on a porous flat plate at a nominal Mach number of 3.0 and a Reynolds number of approximately 4×10^6. Both air and helium were used as the coolants. The results indicate that mass transfer cooling of the turbulent boundary layers is very effective, especially when helium is used as the coolant. Simple film theory is found to be in qualitative agreement with present findings for air and helium. Good correlation is found between the air results and the compressible theory of Rubesin. These tests indicate that even if the boundary layer is turbulent, the heat transfer coefficients can be reduced to well below the uncooled laminar heat transfer coefficients.

* This research is supported by the Air Force Office of Scientific Research, Fluid Mechanics Division.

MINUTES OF THE 1956 SPRING MEETING OF THE NEW YORK STATE SECTION, HELD AT THE NEW YORK STATE COLLEGE FOR TEACHERS, ALBANY, NEW YORK, MAY 11 AND 12, 1956

THE thirty-fifth meeting of the New York State Section was held at Albany, New York with New York State College for Teachers acting as host to about 70 registrants. On Friday afternoon the members enjoyed a tour of the Albany link of microwave television and communications relay system located at the Telephone Building. The after-dinner lecture was sponsored jointly by the Section and the Albany Club of Sigma Xi. The speaker was Dr. B. J. Bok of Harvard Observatory. The lecture was entitled "Future Plans for Radio Astronomy in the United States."

Thirteen contributed papers were presented during sessions held Friday and Saturday. On Saturday morning the members had the opportunity to observe a large number of exhibits and demonstrations in physics by High School Teachers of New York State. This portion of the meeting was organized by Professor M. J. Pryor of the State College. The Saturday afternoon session was devoted to a panel discussion on the topic "Physics in the Professions." The titles of invited papers presented during the meeting are listed below:

1. **A Realistic Look at Supply and Demand.** HUGH M. TEMPLETON.
2. **Physics in Medicine.** LEROY L. BARNES.
3. **Physics in Pharmacy.** JOSEPH M. LAPETINA.
4. **Physics in Engineering.** G. HOWARD CARRAGAN. (Paper read by W. A. MCKINLEY.)
5. **Physics in Law.** THOMAS I. DAVENPORT.
6. **Physics in Crime Detection.** CHARLES W. RANKIN.

D. H. TOMBOULIAN, *Secretary*
New York State Section

1. Three-Centimeter Scattering Measurements.* ROBERT M. WHITMER, *Rensselaer Polytechnic Institute, Troy*.—Measurements are being made of the scattering of 3-cm radiation by objects whose phase dimensions ($ka=+2\pi a/\lambda$) are about unity. Exact calculations can be made, but only with very slowly converging series. Transmitter, target, and receiver are spaced by only several feet. The scattered signal is phase modulated by mechanical oscillation of the target, and beat with a part of the source signal which is brought to the receiver through a cable. The beating signal is independent of azimuth of receiver, and always several times stronger than the direct space signal. The combination of small spacing of

units and large beating signal greatly reduces difficulties with reflections from walls, and also permits measurements to very small azimuth angles—perhaps to zero azimuth.

* This work supported by the Research Corporation.

2. Randomness in Cosmic Ray Events. A. T. GOBLE, *Union College, Schenectady.*—The arrival of cosmic-ray events is generally considered to be random in time. The determination of whether this is true or not may help in understanding the origin of cosmic rays. Instrumentation of an experiment to test the possibility of the existence of some cases of a time correlation of the order of 10^{-3} to 0.5 sec is described. Cosmic-ray events observed by a scintillation detector are recorded by familiar scaling circuits. In addition, the number of doublet, or more, and the number of quadruplet, or more, events occurring in a given interval of the order of 0.5 sec are recorded. Any excess over the number expected for random arrival indicates the existence of a time correlation. The behavior of the last stage of a series of two binary counters and of a series of three counters on resetting serves to indicate a doublet or quadruplet event.

3. A Double Scintillation Gamma-Ray Coincidence Spectrometer of Short Resolving Time. S. B. HILLIER, J. V. ROBINSON,* AND S. C. FULTZ, *Rensselaer Polytechnic Institute, Troy.*—A double scintillation gamma-ray coincidence spectrometer has been constructed in the Physics Department at Rensselaer Polytechnic Institute. The instrument consists of a low-speed and a high-speed coincidence channel which are connected in parallel. The low-speed channel consists of two pulse-height analyzers connected in coincidence and having a resolving time of 3.0×10^{-7} sec. The high-speed channel has no provision for pulse analysis, but measures coincidences between detected pulses with a resolving time at 2.0×10^{-8} sec or less. An additional coincidence circuit records coincidences occurring between the two channels. Provision is made for adding fixed amounts of delay in one side of the high-speed channel. The instrument is to be used to investigate the half-lives of isomeric states in nuclei. Performance of the instrument will be illustrated by curves.

* With Bell Aircraft Corporation, Buffalo, New York.

4. Radio Astronomy Program at Rensselaer Polytechnic Institute. ROBERT FLEISCHER, *Rensselaer Polytechnic Institute, Troy.*—A radio astronomy observatory is being developed on a site 16 miles east of Troy in the township of Grafton. The initial programs of this observatory will concern (a) measurement of variations in ionospheric absorption near 25 Mc, and (b) determination of the apparent motions of sources of solar outbursts at approximately 500 Mc. The ionospheric absorption program will make use of a stationary broadside array directed to the zenith. Radiation from the galaxy, sweeping through the antenna beam once each sidereal day, will provide a continuously repeated source of background radiation. Variations in the absorption of the ionosphere will result in deviations from the normal daily intensity-time curve. The program on solar outbursts will involve an interferometer with two ten-foot reflectors separated by 250 m. The lobe pattern of the interferometer will be swept in angle by varying the relative phase delay between the antennas and the common receiver. The changing phase angle of maximum signal will indicate the apparent motion, relative to the sun, of sources smaller than a single lobe. It is intended to do this eventually on more than one frequency simultaneously. The project is supported by a special grant from the Trustees of Rensselaer Polytechnic Institute, and involves the active cooperation of a number of workers.

5. A Microwave Probe for Detection of either Electric or Magnetic Fields. ROBERT TALHAM, *New York State College for Teachers, Albany.*

6. Ping-Pong Balls and the Band Theory of Solids. D. K. BAKER, *Union College, Schenectady.*—A simple apparatus has been constructed for lecture-room demonstration of the important features of the band theory of solids. Such principles associated with semiconductors as holes, p type, n type, impurity levels, photoconduction, and others will be demonstrated.

7. Angular Correlation of Gamma Radiation from Sc^{46} and Co^{60}. A. DUNEER, R. LIEDTKE,* AND W. A. MCKINLEY, *Rensselaer Polytechnic Institute, Troy.*—Apparatus for studying the gamma-gamma angular correlation of nuclear radiations has been constructed and used in the study of the radiations from Sc^{46} and Co^{60} in different chemical forms. A fast coincidence circuit ($\tau=2\times10^{-8}$ sec), minimizing accidentals, is combined with a slow coincidence circuit ($\tau=3\times10^{-6}$ sec) and voltage discriminator which eliminate small photomultiplier pulses. Both NaI(Tl) and anthracene detectors have been used. The isotopes have been studied in the chemical forms: (1) solid chloride, (2) chloride in aqueous solution, and (3) hydroxide. No change of correlation due to environmental influence has been found in these substances within the experimental error. Typical results are those for the Sc^{46} compounds given in terms of the anisotropy, $A=N(180°)/N(90°)-1$.

Aqueous solution	$ScCl_3$	0.1677 ± 0.0044
Solid	$Sc(OH)_3$	0.1614 ± 0.0038
Solid	$ScCl_3$	0.1638 ± 0.0038
Theoretical for isolated nucleus		0.1667.

* Now at Nuclear Development Associates, White Plains, New York.

8. Innerbremsstrahlung from Fe^{55}. J. P. NEISSEL* AND W. A. MCKINLEY, *Rensselaer Polytechnic Institute, Troy.*—The inner bremsstrahlung spectrum of Fe^{55} has been studied by pulse-height analysis using a NaI(Tl) scintillation spectrometer in the energy range of 38 kev to 246 kev. Comparison with theory has been made using the calculations of Morrison and Schiff[1] and recent calculations by Glauber and Martin.[2] The latter have taken into account contributions from $1S$ and $2P$ electrons with screening and relativistic corrections. Agreement with Morrison and Schiff is good down to 52 kev while agreement with Glauber and Martin is good down to 38 kev with a little discrepancy in the region of 75 kev. The experimental data were corrected for background, and the theoretical curves were distorted to account for absorption, efficiency, Compton effect, escape of iodine K x-ray, and resolution of the instrument.

* Now at General Electric Company, Schenectady, New York.
[1] P. Morrison and L. Schiff, Phys. Rev. **58**, 24 (1940).
[2] R. J. Glauber and P. D. Martin, Phys. Rev. **95**, 572 (1954), and private communication.

9. A Beta-Gamma Coincidence Spectrometer.* R. L. HICKOK, D. A. NEAL,† AND S. C. FULTZ, *Rensselaer Polytechnic Institute, Troy.*—A beta-gamma coincidence spectrometer has recently been constructed in the Physics Department at Rensselaer Polytechnic Institute. The instrument is capable of analyzing beta or gamma spectra independently or may be used for beta-gamma coincidence studies. Beta spectra are resolved by a thick magnetic lens with a momentum resolution of 4% at a transmission of ½%. The energy range covered by the instrument is from 3.5 Mev down to 20 kev. Gamma spectra are determined by pulse analysis from a scintillation detector. The resolution of the gamma spectrometer is 7.3% at an energy of 660 kev. Calibration spectra and spectra of isotopes under study will be shown.

* Assisted in part by a Frederick Gardner Cottrell grant from the Research Corporation.
† Now at E. I. DuPont Company, Wilmington, Delaware.

10. Structure of Triammino Chromiumtetroxide by ... Diffraction.* EUGENE H. MCLAREN, *New York State Colleg Teachers, Albany.*—The structure of crystalline $(NH_3)_3$...

has been determined by use of x-ray diffraction techniques. The specimen studied was monoclinic, belonging to space group $C_{2h}^5-p2_1/c$ and with axes $a=15.21$ A, $b=7.67$ A, $c=9.88$ A and the monoclinic angle $\beta=97.4$ A. Eight molecules were contained in the unit cell, arranged in two nonequivalent sets of general four-fold positions. Discrete monomeric molecules were found, which may be best described in terms of distorted octahedra, with three of the positions filled by ammino groups, two occupied by oxygen atoms, and the sixth being spanned by two oxygen atoms. Distance between nearest oxygen atoms within a molecule, 1.31 A, indicates superoxide ions. Other average distances found were 1.91 A for Cr−O and 2.01 A for Cr−N. Stability of the crystal is interpreted in terms of the favorable hydrogen bonding conditions found throughout the material.

* This paper is based on doctoral thesis research carried on at Washington University, St. Louis, Missouri, under the direction of Dr. Lindsay Helmholtz.

11. Ionization of Air by Ra, Po, and P^{32} at Distances Close to the Radioactive Surface. ROLAND ALLEN* AND HERTA R. LENG, *Rensselaer Polytechnic Institute, Troy.*—M. P. Malsallez[1] described maxima and minima of ionization observed at distances less than 1 mm from radioactive surfaces. He explained his observations with the geometry and polarity of his ionization chamber. An ionization chamber will be described where the variables mentioned by this author have been eliminated. When P^{32} was used and only electrons entered the chamber, the ionization current was constant. For Ra we obtained a minimum at 0.07 mm, a maximum at 0.5 mm. Similar results were obtained for Po. We suggest the interpretation that the minima are due to slow electrons arising from energy losses of alpha particles and recoil nuclei inside the source, while the maxima occur at the end of the range of the recoiling nuclei. The distances measured are in agreement with measurements with other methods of previous investigators.

* Now at Siena College, Loudonville, New York.
[1] M. P. Malsallez, Revue Generale de Electricité, March, 1947.

12. Course Adaptations in General Physics at R.P.I., EDWARD L. LONG, *Rensselaer Polytechnic Institute, Troy.*—Students taking the courses in general physics at R.P.I. present a varied picture with respect to their precollege preparation, their backgrounds, and their native abilities. This paper described how R.P.I. is facing these problems.

13. A Simple Formula for Ranking Opinions Concerning Areas of Emphasis in Science General Education Course Content. L. WALTER SCHULTZE, *New York State College for Teachers, Albany.*—The selection of areas of emphasis among basic concepts usable in science general education courses becomes more difficult as we continue to expand the horizons of fundamental knowledge. This selection is further complicated when the opinions of more than one person enter into the determination. Evaluation of each topic as to whether it is essential, desirable, or unnecessary permits consolidation of these opinions. To establish comparable scores, based upon frequency of response, would require each participant to express an opinion for each topic. This is not always practicable. Furthermore, the character of the topics places a heavy positive bias upon these opinions. In order to circumvent the first difficulty, the frequency of responses in each category, for each topic, can be converted to a percentage. To minimize the positive bias, the following formula has been found useful: Score (for each topic) $=2E-D-2U$, where E, D, and U represent the percent responses for essential, desirable, and unnecessary, respectively. These scores provide a potential range of plus 200 to minus 200. In a recent study, 53 science teachers ranked 89 science topics over a range of scores from plus 168 to minus 102.

MINUTES OF THE MEETING OF THE DIVISION OF HIGH-POLYMER PHYSICS HELD AT THE UNIVERSITY OF WISCONSIN, MADISON, WISCONSIN, JUNE 20–21, 1956

ON 20 and 21 June 1956 the Division of High-Polymer Physics presented two symposia at the University of Wisconsin, Madison, Wisconsin. The first, which was sponsored jointly with the 30th National Colloid Symposium of the Division of Colloid Chemistry, American Chemistry Society, was on Diffusion in Liquids and Polymers. The second symposium, held on the next day, was on Flow Processes in Polymers. The programs of the symposia were arranged by a committee of the Division consisting of John D. Ferry, S. G. Weissberg, T. G. Fox, F. A. Long, and L. Mandelkern. Titles of the papers presented in the symposia follow:

Symposium on Diffusion in Liquids and Polymers

(F. A. LONG presiding)

Introductory Remarks. F. A. LONG
Equations of Transport in Multi-Component Systems. JOHN G. KIRKWOOD
Optical Methods for Studying Diffusion in Liquids. GERSON KEGELES
Soret Diffusion with the Aid of Rayleigh Interferometry. L. G. LONGSWORTH
Determination of Diffusion Coefficients for Liquid Systems by Measurements of Free Diffusion. LOUIS J. GOSTING
Permeability of Membranes. HENRY EYRING
Some Properties of Diffusion Coefficients in Polymers. R. M. BARRER
Some Aspects of the Permeation of Vapors through Polymer Films. M. SZWARC
Influence of the Glass Transition on Diffusion in Polymers. F. A. LONG

Symposium on Flow Processes in Polymers

(T. G. Fox presiding)

Statistical Mechanics and Thermodynamics of Flow Processes. C. F. CURTISS
Characteristic Phenomena Associated with Flow Processes in Polymers. JOHN D. FERRY
Molecular Entanglements and Their Effect on Viscous and Elastic Deformation of Polymers. F. BUECHE
Elementary Process of Flow. S. GRATCH
Details of Flow Processes in Dilute Polymer Solutions. B. ZIMM
Correlation between the Flow Behavior of a Polymer Molecule in Dilute Solution and in Bulk. L. MANDELKERN

W. JAMES LYONS, *Secretary-Treasurer*
Division of High-Polymer Physics

New Regulations Pertaining to the "Student Concession"

THE "student concession" is the alleviation of the financial burden of Membership in the American Physical Society, granted to newly elected Members who are students in recognized institutions of learning. It was instituted in 1952, and our Council has now (April 27, 1956) made important changes in the rules that define it and in the stipulations that define eligibility to it. Henceforth it shall consist (a) in a reduction of the dues from fifteen dollars to ten dollars, and (b) in the privilege of obtaining *one* journal, among those made available to all members on "membership subscription," without extra payment over and above the dues. It will be granted for one year only, and this must be the first year of Membership.

To be eligible for the "student concession," a candidate must (1) be a full-time student in a recognized institution of learning, and (2) present a certification by one of his sponsors that he is in fact such a student. On the nomination forms which have been printed during the last couple of years there is a certification (on the reverse side) which the sponsor must sign: it is however to be borne in mind that the words "bona fide student regularly enrolled" are now to be interpreted as meaning "full-time student," and that the special privilege is now limited to one year. Unfortunately there are many nomination forms of more ancient vintage still floating around. If one of these is used, the certification must be made in a covering letter signed by one of the sponsors, and this covering letter must be mailed in the same envelope as the nomination form.

These rules and stipulations will apply to candidates elected to Membership in November 1956 and thenceforward. Nomination forms for a number of candidates have been received at the office of the Society for action at the November meeting: if the sponsors of such a candidate wish to propose him for the "student concession" but have reason to think that stipulation (2) has not been fulfilled, or if they did certify him but he is ineligible under the strict formulation of stipulation (1), they should at once recall his nomination form from this office and take heed of these stipulations before sending it back. Candidates who were elected to Membership at any time in the first six months of 1956 and who were granted the "student concession" for 1956 have a right to retain it for 1957: in such case it consists simply of the privilege of receiving one journal on membership subscription without extra payment over and above dues, and the dues themselves stand at the normal figure of fifteen dollars.

The American Physical Society

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COUNCIL

The President, Vice-President, Secretary, Treasurer, Managing Editor, the three Past Presidents most recently retired from office, eight elected members, and all Past Presidents first elected to the office of President prior to December 1932 constitute the Council which shall have general charge of the affairs of the Society.

Past Presidents now on Council: W. F. G. Swann, H. A. Bethe and R. T. Birge.

Elected Members of the Council: L. I. Schiff, W. Shockley, John Bardeen, A. O. Nier, F. Seitz, A. M. Weinberg, S. K. Allison, and N. F. Ramsey.

Please cut along this line

(To be sent to Mrs. Dorothy C. Johnson, Enrico Fermi Institute, 5630 South Ellis Avenue, Chicago 37, Illinois.

I EXPECT to attend the dinner of the American Physical Society at seven o'clock on Friday evening, November 23. My party will comprise .... persons.

(*Name*) .....

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(If you want your tickets mailed to you, send a check, made out to American Physical Society, for $3.50 per plate together with a stamped self-addressed envelope.)